

# Star formation<sup>\*</sup> in 3CR radio galaxies and quasars at $z < 1$

Christian Westhues<sup>1,2</sup>, Martin Haas<sup>1</sup>, Peter Barthel<sup>3</sup>, Belinda J. Wilkes<sup>4</sup>, S.P. Willner<sup>4</sup>,  
Joanna Kuraszkiewicz<sup>4</sup>, Pece Podigachoski<sup>3</sup>, Christian Leipski<sup>5</sup>, Klaus Meisenheimer<sup>5</sup>,  
Ralf Siebenmorgen<sup>6</sup>, and Rolf Chini<sup>1,7</sup>

## ABSTRACT

Using the *Herschel Space Observatory* we have observed a representative sample of 87 powerful 3CR sources at redshift  $z < 1$ . The far-infrared (FIR, 70–500  $\mu\text{m}$ ) photometry is combined with mid-infrared (MIR) photometry from the *Wide-Field Infrared Survey Explorer (WISE)* and catalogued data to analyse the complete spectral energy distributions (SEDs) of each object from optical to radio wavelength. To disentangle the contributions of different components, the SEDs are fitted with a set of templates to derive the luminosities of host galaxy starlight, dust torus emission powered by active galactic nuclei (AGN) and cool dust heated by stars. The level of emission from relativistic jets is also estimated, in order to isolate the thermal host galaxy contribution. The new data are in line with the orientation-based unification of high-excitation radio-loud AGN, in that the dust torus becomes optically thin longwards of 30  $\mu\text{m}$ . The low excitation radio galaxies and the MIR weak sources represent MIR- and FIR-faint AGN population different from the high-excitation MIR-bright objects; it remains an open question whether they are at a later evolutionary state or an intrinsically different population. The derived luminosities for host starlight and dust heated by star formation are converted to stellar masses and star formation rates (SFR). The host-normalized SFR of the bulk of the 3CR sources is low when compared to other galaxy populations at the same epoch. Estimates of the dust mass yield a 1–100 times lower dust/stellar mass ratio than for the Milky Way, indicating that these 3CR hosts have very low levels of interstellar matter explaining the low level of star formation. Less than 10% of the 3CR sources show levels of star formation above those of the main sequence of star forming galaxies.

*Subject headings:* galaxies: active, infrared: galaxies, radio continuum: galaxies

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<sup>1</sup> Astronomisches Institut, Ruhr-Universität Bochum, Universitätsstr. 150, D-44801 Bochum, Germany

<sup>2</sup>email: christian.westhues@astro.rub.de

<sup>3</sup> Kapteyn Astronomical Institute, University of Groningen, NL-9747 AD Groningen

<sup>4</sup> Harvard-Smithsonian Center for Astrophysics, Garden St. 60, Cambridge, MA 02138, USA

<sup>5</sup> Max-Planck-Institut für Astronomie (MPIA), Königstuhl 17, D-69117 Heidelberg, Germany

<sup>6</sup> European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching b. München, Germany

<sup>7</sup> Instituto de Astronomía, Universidad Católica del Norte, Avenida Angamos 0610, Casilla 1280, Antofagasta, Chile

## 1. Introduction

In the current paradigm of AGN evolution, galaxy collisions and mergers lead to the genesis of powerful radio sources (Heckman *et al.* 1986). Based on FIR studies with the Infrared Astronomical Satellite (*IRAS*) in the 1980s, the Palomar-Green (PG) quasars appear to be preceded or accompanied by violent dust-enshrouded starburst activity (Sanders *et al.* 1988, 1989; Rowan-Robinson 1995). Refined Infrared Space Observatory (*ISO*) photometry in the 1990s indicates a potential evolution from FIR-bright to FIR-faint AGN states (see Haas *et al.* 2003).

Searching for the unbeamed counterparts of the quasar population in the medium-redshift ( $0.5 <$

$z < 1$ ) sample from the Revised Third Cambridge Catalogue of Radio Sources (3CR), Barthel (1989, 1994) proposed the orientation-based unification scheme of quasars and high-excitation radio galaxies (HERGs). Consensus is growing that this scheme is basically valid for sources with high radio power ( $P_{178\text{ MHz}} > 10^{28} \text{ W Hz}^{-1}$ ).

The sample is subdivided by the classification criteria based on radio and optical properties. In compact steep spectrum (CSS) sources the radio emission is restricted to regions of less than 20kpc. Fanaroff-Riley Class I (FRI) sources show edge-dimmed radio lobes, while in FRII sources the lobes are more bright at the edge. The type-1 sources have optical bright continua and broad emission lines and are called Broad-Line Radio Galaxies (BLRG) at low luminosity. The high luminosity Flat-Spectrum-Quasars (FSQs) show flat radio spectra in  $F_\nu$  in contrast to Steep-Spectrum-Quasars (SSQs) with the dividing spectral index  $\alpha = 0.5$  measured at a few GHz. Type-2 sources show only narrow emission lines and have weak optical continua. High-Excitation RGs (HERGs) have  $[\text{O III}]/[\text{O II}] > 1$ , Low-Excitation RGs (LERGs) have  $[\text{O III}]/[\text{O II}] < 1$  ( $\lambda_{[\text{O II}]} = 3727 \text{ \AA}$ ,  $\lambda_{[\text{O III}]} = 5007 \text{ \AA}$ ).

The 3CR radio sources can be sub-divided into many different classes (e.g. quasars and radio-galaxies), and it has early been questioned by demographic arguments that every edge-brightened double-lobe FRII radio galaxy is a misaligned hidden quasar. At low-redshift ( $z < 0.5$ ) where the radio power of the 3CR sample reaches down to  $P_{178\text{ MHz}} \approx 10^{26} \text{ W Hz}^{-1}$ , narrow-line radio galaxies outnumber the quasars and broad-line radio galaxies (BLRGs), mainly due to the contribution of low-excitation radio galaxies (LERGs) (Laing *et al.* 1983; Singal 1993).

Based on mid-infrared (MIR) observations, with VISIR, ISOCAM (van der Wolk *et al.* 2010; Siebenmorgen *et al.* 2004) and Spitzer (Ogle *et al.* 2006), the LERGs and a few HERGs are MIR-weak, indicating that they either do not possess high accretion power comparable to the MIR-strong HERGs and quasars/BLRGs or that they are more strongly extinguished. FIR observations may be able to discriminate between the two scenarios, but in view of the expected faintness such observations have not been performed so far; only a few dozen bright HERGs and quasars/BLRGs,

have been detected in the FIR with ISO<sup>1</sup> as compiled by Haas *et al.* (2004).

In this work a sample of 87 sources from the 3CR catalogue (Edge *et al.* 1959; Bennett 1962; Laing *et al.* 1983; Spinrad *et al.* 1985) is studied. With the Herschel Space Observatory (Pilbratt *et al.* 2010) we measured the FIR/submm SEDs of the 3CR sources in two complementary proposals, one at redshift  $1 < z < 3$  (PI: Barthel, Barthel *et al.* 2012; Podigachoski *et al.* 2015a,b) and one at medium ( $0.5 < z < 1$ ) and low ( $z < 0.5$ ) redshift (PI: Haas).

We here present sensitive Herschel PACS/SPIRE 70–500  $\mu\text{m}$  photometry of the representative 3CR sample at low and medium-redshift. The FIR properties of this 3CR sample were already measured with the previous IR satellites (IRAS: Heckman *et al.* 1992, 1994; Hes *et al.* 1995; Hoekstra *et al.* 1997; ISO: van Bemmell *et al.* 2000; Fanti *et al.* 2000; Polletta *et al.* 2000; Meisenheimer *et al.* 2001; Andreani *et al.* 2002; Haas *et al.* 2004 and the Spitzer Space Telescope: Haas *et al.* 2005; Ogle *et al.* 2006; Cleary *et al.* 2007). The new FIR observations with Herschel benefit from the higher spatial resolution and sensitivity of the instruments.

We here analyse the full optical to radio SEDs, also combined with *WISE* 3–22  $\mu\text{m}$  photometry. The purpose is to explore dust emission in the FIR for the most powerful radio-loud AGN, to provide constraints on the star forming activity and to investigate the evolutionary status of their host galaxies.

We adopt a standard  $\Lambda\text{CDM}$  cosmology ( $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ,  $\Omega_\Lambda = 0.73$ , and  $\Omega_m = 0.27$ , Spergel *et al.* 2007).

## 2. Sample

### 2.1. Medium-redshift sample $0.5 < z < 1$

The sample properties for 3CR-sources at medium-redshifts, which were observed by Herschel in the two open time programs from the *OT1\_mhaas\_2* and *OT1\_jstevens\_1* proposals, are given in Table 1. From the 48 sources at  $0.5 < z <$

<sup>1</sup>Due to the large ISO beam (FWHM = 90'' at 160  $\mu\text{m}$ ), the “high” flux of some 3C-sources, e.g. 3C 20 and 3C 47, contains contribution from nearby sources revealed by our Herschel maps

1 in the 3CR catalogue a representative subset of 39 was observed. The sources are selected to be brighter than 10 Jy at a frequency of 178 MHz (Laing *et al.* 1983). The sources that were not observed with Herschel don't bias the remaining sub-sample because their types are well represented. For the observed sources MIR photometry and/or spectroscopy from the Spitzer Space Telescope can be found in Ogle *et al.* 2006 and Cleary *et al.* 2007. Sources in the 3CR catalogue but not observed by Spitzer are 2 FSQs (3C 345, 3C 454.3), 1 SSQ (3C 275.1), 4 HERGs (3C 34, 3C 217, 3C 247, 3C 277.2) and 1 LERG (3C 41). Two HERGs, 3C 175.1 and 3C 220.3, have been removed from the analysis. The former has insufficient ancillary data in the literature, and the latter acts as gravitational lens for a submillimetre galaxy at  $z = 2.2$  (Haas *et al.* 2014).

Thus a sample of 37 representative sources has been analysed, which consists of 7 FSQs (6 of them CSS), 7 SSQs (one BLRG), 22 HERGs (4 CSS) and 1 LERG.

## 2.2. Low-redshift sample $z < 0.5$

The 3CR sample properties at low-redshifts are shown in Table 2. It contains 48 sources at  $z < 0.5$ , of which 40 sources are included in the 3CR catalog (Laing *et al.* 1983). From the Spinrad *et al.* 1985 version of 3CR-sources, which extends to lower declinations, 4 additional sources belong to this sample. Mainly taken from the *OT1-mhaas-2* proposal, the whole Herschel Science Archive (HSA) was searched for 3C-sources and the complete Herschel-observed list was collected, which were observed also in the *OT1-pogle01-1*, *OT1-rmushotz-1*, *OT1-lho-1* and *OT1-dfarrah-1* proposals.

For all of them Spitzer MIR data are available. 23 sources were observed in the flux limited sample of Ogle *et al.* (2006) with  $S_{178\text{ MHz}} > 15\text{ Jy}$ . Four remaining sources from the Ogle sample were planned but not observed with Herschel. The rest of 25 sources were selected from samples already seen with Spitzer by Haas *et al.* (2005) (also observed by the ISO satellite), by Cleary *et al.* (2007) and Hardcastle *et al.* (2009) (X-ray selection).

For the analysis the sample is subdivided into 4 FSQs (thereof 3 BLRGs), 10 SSQs (thereof 6

BLRGs), 19 HERGs and 15 LERGs. All but 6 sources (3 HERGs and 3 LERGs) in this sample are morphologically classified as FR II sources (Fanaroff and Riley 1974).

## 3. Data

For some objects of the medium-redshift sample a revision of the coordinates given in NED was necessary. We checked the positions given by Laing *et al.* (1983) and inspected WISE images. Positions from high resolution radio maps (Mullin *et al.* 2006; Haas *et al.* 2014) or positions seen with Chandra at 2–8 keV were taken whenever available. For the low-redshift sample the coordinates were revised to match Willot's positions<sup>2</sup>. Core positions from high resolution radio maps from VLA observation by Gilbert *et al.* (2004) were taken whenever available. The revised coordinates are indicated by footnotes in Tables 1 and 2. Also the classifications for 3C 343 and 3C 455 from NED were altered from QSR to HERG based on classification given by Véron-Cetty and Véron (2010).

### 3.1. Herschel PACS and SPIRE

The data were downloaded from the Herschel Science Archive (HSA) within the framework of the Herschel Interactive Processing Environment (HIPE version 11.1.0, Ott 2010). For source extraction the tool SourceExtractor from Bertin and Arnouts (1996) was used and additional routines were developed in the Interactive Data Language (IDL) using the IDL Astronomy Library (Landsman 1993).

#### 3.1.1. Observations

For the Photoconductor Array Camera and Spectrometer (PACS) (Poglitsch *et al.* 2010) the *Scan-Map* observational mode was chosen to observe the sources photometrically at 70/100/160  $\mu\text{m}$  (blue/green/red). In a single-scan two filters (blue-red or green-red) were observed simultaneously. Often a cross-scan was done, with two consecutive single-scans with different scan directions. With the first scan in blue-red and the second in green-red combination the whole spectral range of PACS is covered, and the double scan in

<sup>2</sup><http://3crr.extragalactic.info/cgi/database>

Table 1: 3CR sources  $0.5 < z < 1$  observed with Herschel

Name	RA [J2000]	Dec [J2000]	Redshift	$D_L$ [Mpc]	Type	Proposal-ID <sup>a</sup>	PACS-OBSID	SPIRE-OBSID
3C006.1	00 16 31.1	+79 16 50	0.8404	5193	HERG	1	1342262061/62	
3C022.0	00 50 56.3	+51 12 03	0.9360	5935	BLRG	2	1342237866/67	
3C049.0	01 41 09.1	+13 53 28	0.6207	3568	HERG <sup>b</sup>	1	1342261865/66	
3C055.0	01 57 10.5	+28 51 38	0.7348	4392	HERG	1	1342261794/95	1342261703
3C138.0	05 21 09.9	+16 38 22	0.7590	4578	QSR <sup>b</sup>	1	1342267270/71	1342268340
3C147.0	05 42 36.1	+49 51 07	0.5450	3048	QSR <sup>b</sup>	1	1342268972/73	
3C172.0	07 02 08.3	+25 13 53 <sup>c</sup>	0.5191	2876	HERG	1	1342268994/95	
3C175.0	07 13 02.4	+11 46 15	0.7700	4665	QSR	1	1342269004/05	
3C175.1	07 14 04.7	+14 36 22	0.9200	5820	HERG	2	1342242694/95	1342230780
3C184.0	07 39 24.2	+70 23 11 <sup>c</sup>	0.9940	6406	HERG	2	1342243742/43	1342229126
3C196.0	08 13 36.0	+48 13 03	0.8710	5436	QSR	1	1342254180/81	
3C207.0	08 40 47.6	+13 12 24	0.6806	4009	QSR	1	1342254575/76	
3C216.0	09 09 33.5	+42 53 46	0.6699	3929	QSR <sup>b</sup>	1	1342254561/62	1342255115
3C220.1	09 32 39.6	+79 06 32	0.6100	3498	HERG	1	1342254194-96	
3C220.3	09 39 23.8	+83 15 26 <sup>c</sup>	0.6800	3997	LENS	1	1342221818/19	1342254521
3C226.0	09 44 16.5	+09 46 17 <sup>c</sup>	0.8177	5030	HERG	1	1342255958/59	1342255165
3C228.0	09 50 10.8	+14 20 01	0.5524	3106	HERG	1	1342255462-64	
3C254.0	11 14 38.7	+40 37 20	0.7366	4418	QSR	1	1342255900/01	
3C263.0	11 39 57.0	+65 47 49	0.6460	3755	QSR	1	1342255428-30	
3C263.1	11 43 25.1	+22 06 56	0.8240	5078	HERG	1	1342255685-87	
3C265.0	11 45 29.0	+31 33 47 <sup>c</sup>	0.8110	4978	HERG	1	1342255485/86	
3C268.1	12 00 24.5	+73 00 46 <sup>c</sup>	0.9700	6214	HERG	2	1342245706/07 1342247316/17	1342229628
3C280.0	12 56 57.8	+47 20 20 <sup>c</sup>	0.9960	6426	HERG	2	1342233434/35	1342232704
3C286.0	13 31 08.3	+30 30 33	0.8499	5275	QSR <sup>b</sup>	1	1342259326/27	1342259451
3C289.0	13 45 26.4	+49 46 33	0.9674	6196	HERG	2	1342233495/96	1342232711
3C292.0	13 50 41.9	+64 29 36 <sup>c</sup>	0.7100	4218	HERG	1	1342257595-97	
3C309.1	14 59 07.6	+71 40 20	0.9050	5698	QSR <sup>b</sup>	1	1342259354-57	
3C330.0	16 09 34.9	+65 56 38 <sup>c</sup>	0.5500	3082	HERG	1	1342261369/70	
3C334.0	16 20 21.8	+17 36 24	0.5551	3118	QSR	1	1342261319/20	1342263861
3C336.0	16 24 39.1	+23 45 12	0.9265	5868	QSR	1	1342261324-27	
3C337.0	16 28 52.5	+44 19 07 <sup>c</sup>	0.6350	3674	HERG	1	1342261350-53	
3C340.0	16 29 36.6	+23 20 13 <sup>c</sup>	0.7754	4702	HERG	1	1342261321-23	
3C343.0	16 34 33.8	+62 45 36	0.9880	6356	HERG <sup>b,c</sup>	2	1342234218/19	
3C343.1	16 38 28.2	+62 34 44	0.7500	4511	HERG <sup>b</sup>	1	1342261364-66	
3C352.0	17 10 44.1	+46 01 29	0.8067	4937	HERG	1	1342256219-21	
3C380.0	18 29 31.8	+48 44 46	0.6920	4081	QSR <sup>b</sup>	1	1342257947/48	
3C427.1	21 04 06.8	+76 33 11	0.5720	3230	LERG	1	1342261377/78	
3C441.0	22 06 04.9	+29 29 20	0.7080	4193	HERG	1	1342221833-36	
3C455.0	22 55 03.9	+13 13 34	0.5430	3026	HERG <sup>b,c</sup>	1	1342258014-17	

<sup>a</sup>1=OT1\_mhaas\_2, 2=OT1\_jstevens\_1<sup>b</sup>CSS<sup>c</sup>coordinates/classification revised

Table 2: 3CR sources  $z < 0.5$  observed with Herschel

Name	RA [J2000]	Dec [J2000]	Redshift	$D_L$ [Mpc]	Type	Proposal-ID <sup>a</sup>	PACS-OBSID	SPIRE-OBSID
3C020.0	00 43 09.2	+52 03 36 <sup>b</sup>	0.1740	804	HERG	1		1342265338
3C031.0	01 07 24.9	+32 24 45	0.0170	66	LERG <sup>c</sup>	3	1342224218/19	1342236245
3C033.0	01 08 52.9	+13 20 14 <sup>b</sup>	0.0597	252	HERG	1	1342261863/64	
3C033.1	01 09 44.3	+73 11 57 <sup>b</sup>	0.1810	842	BLRG	1	1342261944-46	
3C035.0	01 12 02.3	+49 28 36 <sup>b</sup>	0.0670	286	HERG	1	1342261413-16	
3C047.0	01 36 24.4	+20 57 28 <sup>b</sup>	0.4250	2252	QSR	1		1342261707
3C048.0	01 37 41.3	+33 09 35	0.3670	1892	QSR <sup>d</sup>	1		1342261702
3C079.0	03 10 00.1	+17 05 59 <sup>b</sup>	0.2559	1244	HERG	1	1342262229/30	
3C098.0	03 58 54.4	+10 26 03	0.0305	126	HERG	1	1342267198/99	
3C109.0	04 13 40.4	+11 12 15 <sup>b</sup>	0.3056	1529	BLRG	1	1342267272/73	1342266668
3C111.0	04 18 21.3	+38 01 36	0.0485	205	BLRG	4	1342239439/40	1342229105
3C120.0	04 33 11.1	+05 21 16	0.0330	138	BLRG	4	1342241955/56	1342239936
3C123.0	04 37 04.4	+29 40 14	0.2177	1037	LERG	1	1342267256-59	
3C153.0	06 09 32.5	+48 04 15	0.2769	1367	LERG	1	1342267224-27	
3C171.0	06 55 14.8	+54 08 57 <sup>b</sup>	0.2384	1152	HERG	1	1342267228/29	
3C173.1	07 09 18.2	+74 49 32 <sup>b</sup>	0.2921	1453	LERG	1	1342265540/41	
3C192.0	08 05 35.0	+24 09 50	0.0597	260	HERG	1	1342254172/73	
3C200.0	08 27 25.4	+29 18 45	0.4580	2475	LERG	1	1342254174-77	
3C219.0	09 21 08.6	+45 38 57	0.1747	815	BLRG	1	1342254559/60	
3C234.0	10 01 49.5	+28 47 09	0.1849	870	HERG	1	1342255459	1342255182
3C236.0	10 06 01.8	+34 54 10 <sup>b</sup>	0.1005	449	LERG	3	1342246697/98	1342246613
						1	1342270912/13	
3C249.1	11 04 13.9	+76 58 58 <sup>b</sup>	0.3115	1566	QSR	5	1342221763-66	1342229630
3C268.3	12 06 24.7	+64 13 37	0.3717	1928	BLRG <sup>d</sup>	1	1342255424/25	
3C273.0	12 29 06.7	+02 03 09	0.1583	734	QSR	6		1342234882
3C274.1	12 35 26.7	+21 20 35	0.4220	2246	HERG	1	1342258032-35	
3C285.0	13 21 17.9	+42 35 15	0.0794	349	HERG	1	1342258514/15	1342256880
3C300.0	14 22 59.8	+19 35 37 <sup>b</sup>	0.2700	1331	HERG	1	1342262509-12	
3C305.0	14 49 21.6	+63 16 14	0.0416	177	HERG <sup>c</sup>	3	1342223959/60	1342234915
3C310.0	15 04 57.1	+26 00 58 <sup>b</sup>	0.0538	233	LERG <sup>c</sup>	3	1342235116/17	1342234778
3C315.0	15 13 40.1	+26 07 31	0.1083	484	HERG <sup>c</sup>	3	1342224636/37	1342234777
3C319.0	15 24 04.9	+54 28 06 <sup>b</sup>	0.1920	903	LERG	1	1342231879-82	
3C321.0	15 31 43.5	+24 04 19	0.0961	426	HERG	1		1342261679
3C326.0	15 52 09.1	+20 05 24 <sup>b</sup>	0.0895	395	LERG	3	1342248732/33	1342238327
3C341.0	16 28 04.0	+27 41 39 <sup>b</sup>	0.4480	2406	HERG	1	1342261328/29	
3C349.0	16 59 28.9	+47 02 55 <sup>b</sup>	0.2050	970	HERG	1	1342261354/55	
3C351.0	17 04 41.4	+60 44 30 <sup>b</sup>	0.3719	1927	QSR	5	1342232428-31	1342229147
3C381.0	18 33 46.3	+47 27 03	0.1605	737	BLRG	1	1342261360/61	
3C382.0	18 35 03.4	+32 41 47	0.0579	246	BLRG	1	1342256206/07	
3C386.0	18 38 26.2	+17 11 50 <sup>b</sup>	0.0169	68	LERG <sup>c</sup>	3	1342231672/73	1342239789
3C388.0	18 44 02.4	+45 33 30	0.0917	401	LERG	1	1342261356-59	
3C390.3	18 42 08.9	+79 46 17 <sup>b</sup>	0.0561	239	BLRG	1	1342221871/72	
3C401.0	19 40 25.0	+60 41 36 <sup>b</sup>	0.2011	947	LERG	1	1342256194-97	
3C424.0	20 48 12.0	+07 01 17	0.1270	567	LERG	3	1342233349/50	1342244149
3C433.0	21 23 44.5	+25 04 28 <sup>b</sup>	0.1016	445	HERG <sup>c</sup>	1	1342219391/92	
						3	1342232731/32	1342234675
3C436.0	21 44 11.7	+28 10 19	0.2145	1016	HERG	3	1342235316/17	1342234676
						1	1342257734-37	
3C438.0	21 55 52.3	+38 00 28 <sup>b</sup>	0.2900	1435	LERG	1	1342259246-49	
3C452.0	22 45 48.8	+39 41 16	0.0811	349	HERG	1	1342259368/69	
3C459.0	23 16 35.2	+04 05 18	0.2201	1045	BLRG	3	1342237979/80	1342234756

<sup>a</sup>1=OT1\_mhaas\_2, 2=OT1\_jstevens\_1, 3=OT1\_pogle01\_1, 4=OT1\_rmushotz\_1, 5=OT1\_lho\_1, 6=OT1\_dfarrah\_1<sup>b</sup>coordinates revised<sup>c</sup>FR I<sup>d</sup>CSS

the red filter was combined afterwards to reach a higher sensitivity. For some sources deeper imaging was achieved by the combination of multiple cross-scans.

The Spectral and Photometric Imaging Receiver (SPIRE) (Griffin *et al.* 2010) observes in three bands at 250/350/500  $\mu\text{m}$  (short/mid/long) at once. The *Small-Scan-Map* observational mode was chosen. For the medium-redshift sample the OBSIDs for the 98 PACS scans and 12 SPIRE scan-maps are shown in Table 1. The low-redshift sample was observed in 118 PACS scans and 23 SPIRE maps, OBSIDs are given in Table 2.

### 3.1.2. PACS-Reduction

The reduction of the PACS scan-maps was done in two steps, as bright sources have to be masked during the high-pass filtering (see Popesso *et al.* 2012). In the first step a preliminary image is generated, which is then used to determine the positions for masking with SourceExtractor (only detections with 9 pixels above a  $3\sigma$  threshold are masked).

To minimize correlated noise and to get a good signal-to-noise ratio a pixel fraction of 0.6 and pixel sizes of 1.1'' , 1.4'' and 2.1'' for the 70  $\mu\text{m}$ , 100  $\mu\text{m}$  and 160  $\mu\text{m}$  band was chosen. Additionally the high-pass filter radius was set to 10, 15 and 20 readouts. The multiple scans were then combined with the *mosaic* task in HIPE.

The aperture corrected flux was determined for the pointlike sources in the frame. The target source was assumed to be that closest to and within 7'' of the known source position (as listed in Tables 1 and 2). Images of size  $2' \times 2'$  are shown in Appendix A.2.

We derived the photometric uncertainty as follows: Every frame comes with a coverage map which was used to generate 500 random positions on the map, where the coverage is greater than 75% of its maximum. At these positions the HIPE routine *annularSkyAperturePhotometry* was used to perform aperture photometry with the background calculated in an annulus. Values for aperture and annulus radii (recommended for fluxes < 500mJy) given in Table 3 follow the Herschel Webinar for ‘‘PACS Point Source Photome-

try’’ by Paladini<sup>3</sup>. The Gaussian dispersion of the 500 aperture-corrected fluxes was adopted as the  $1\sigma$  uncertainty for each map (see also Leipski *et al.* 2013), and is listed in Tables 4 and 5. Where no sources could be detected a  $3\sigma$  upper limit is given.

### 3.1.3. SPIRE-Reduction

For the photometry of the SPIRE observations we followed the steps of the ‘‘Recipe for SPIRE Photometry’’<sup>4</sup>. The recommended algorithm for point source photometry is the time-line-fitter, *sourceExtractorTimeline* in HIPE. To determine the positions of sources in the SPIRE maps, we used the level2 products of the observations in the HSA. A source list was generated within HIPE by *sourceExtractorSussexextractor*. The coordinates of these sources were then used to perform the fitting in the timeline data on the level1 products in the HSA. The nearest source within 30'' to the coordinates given in Table 1 and 2 was identified as the 3CR target.

As for the uncertainty determination for the PACS observations, we used 500 randomly generated positions on the SPIRE maps, centered within 23 pixels of the center (138''/230''/322'' for 250  $\mu\text{m}$ /350  $\mu\text{m}$ /500  $\mu\text{m}$ ). At these positions the photometry was carried out in the same manner as for the sources. The dispersion of the distribution again gave the  $1\sigma$  uncertainty or  $3\sigma$  upper limits, which are given in Tables 4 and 5. Images of size  $4' \times 4'$  are shown in Appendix A.2.

<sup>3</sup><https://nhscsci.ipac.caltech.edu/pacs/docs/Webinars/2012-07-13/Paladini>

<sup>4</sup>[http://herschel.esac.esa.int/hcss-doc-13.0/load/spire\\_drg/html/ch06s07.html](http://herschel.esac.esa.int/hcss-doc-13.0/load/spire_drg/html/ch06s07.html)

Table 3: PACS Aperture and Annulus radii

	70 $\mu\text{m}$	100 $\mu\text{m}$	160 $\mu\text{m}$
Aperture radius ["]	5.5	5.6	10.5
Annulus inner radius ["]	20	20	24
Annulus outer radius ["]	25	25	28
Aperture correction	0.61	0.57	0.63

Table 4: 3CR sources  $0.5 < z < 1$  PACS and SPIRE flux densities.  $1\sigma$  uncertainties are given in brackets, upperlimits are  $3\sigma$

Name	Figure	$F_{70}$ [mJy]	$F_{100}$ [mJy]	$F_{160}$ [mJy]	$F_{250}$ [mJy]	$F_{350}$ [mJy]	$F_{500}$ [mJy]
3C006.1	Fig. 4	<14	<15	<30			
3C022.0	Fig. 2	28( 3)		<36			
3C049.0	Fig. 3	16( 4)		27( 7)			
3C055.0	Fig. 3	90( 4)	126( 4)	123( 8)	85( 9)	42( 9)	<42
3C138.0	Fig. 1	47( 4)	49( 5)	58( 10)	64( 11)	70( 15)	103( 14)
3C147.0	Fig. 1	59( 5)	71( 5)	72( 10)			
3C172.0	Fig. 5	<9	<14	<28			
3C175.0	Fig. 2	26( 3)	24( 4)	<45			
3C175.1	Fig. 7	<8		<22	<62	<50	<38
3C184.0	Fig. 3	12( 2)		<24	<31	<22	<23
3C196.0	Fig. 2	24( 3)	18( 4)	<34			
3C207.0	Fig. 1	16( 4)	21( 5)	32( 8)			
3C216.0	Fig. 1	79( 3)	102( 5)	143( 9)	204( 8)	229( 14)	266( 22)
3C220.1	Fig. 5	<8	<12	<18			
3C220.3	Fig. 7	26( 3)	99( 4)	259( 11)	452( 9)	412( 8)	259( 7)
3C226.0	Fig. 3	44( 3)	36( 5)	<19	<31	<42	<42
3C228.0	Fig. 5	<8	<15	<23			
3C254.0	Fig. 2	14( 4)	<15	<27			
3C263.0	Fig. 2	56( 4)	43( 4)	27( 8)			
3C263.1	Fig. 4	<8	<12	<21			
3C265.0	Fig. 3	40( 4)	47( 6)	<41			
3C268.1	Fig. 5	<8		<20	<38	<45	<23
3C280.0	Fig. 3	24( 3)		<31	<38	<32	<40
3C286.0	Fig. 1	36( 4)	41( 4)	59( 7)	76( 11)	84( 13)	112( 15)
3C289.0	Fig. 4	10( 3)		<21	<32	<33	<35
3C292.0	Fig. 5	<7	<11	<18			
3C309.1	Fig. 1	43( 3)	35( 4)	39( 9)			
3C330.0	Fig. 4	<11	<20	<27			
3C334.0	Fig. 2	69( 3)	71( 4)	51( 8)	<40	<33	<67
3C336.0	Fig. 2	<8	<9	<23			
3C337.0	Fig. 5	<6	<9	<13			
3C340.0	Fig. 4	<7	<13	<24			
3C343.0	Fig. 3	58( 2)		73( 11)			
3C343.1	Fig. 4	11( 3)	<17	<21			
3C352.0	Fig. 5	<7	<12	19( 4)			
3C380.0	Fig. 1	69( 4)	94( 5)	149( 9)			
3C427.1	Fig. 6		<6	<18			
3C441.0	Fig. 4	8( 3)	<11	<26			
3C455.0	Fig. 4	<6	<8	<18			

Table 5: 3CR sources  $z < 0.5$  PACS and SPIRE flux densities.  $1\sigma$ -errors are given in brackets, upperlimits are  $3\sigma$

Name	Figure	$F_{70}$ [mJy]	$F_{100}$ [mJy]	$F_{160}$ [mJy]	$F_{250}$ [mJy]	$F_{350}$ [mJy]	$F_{500}$ [mJy]
3C020.0	Fig. 11				58( 19)	50( 16)	<50
3C031.0	Fig. 15		867( 3)	1347( 11)	955( 16)	408( 20)	169( 20)
3C033.0	Fig. 11	161( 4)	194( 4)	179( 8)			
3C033.1	Fig. 10	38( 4)	31( 3)	<39			
3C035.0	Fig. 13	<6	16( 3)	<23			
3C047.0	Fig. 9				<41	<40	<23
3C048.0	Fig. 9				311( 10)	137( 13)	62( 10)
3C079.0	Fig. 11	65( 4)	49( 5)	37( 10)			
3C098.0	Fig. 12	41( 5)	49( 4)	<37			
3C109.0	Fig. 10	158( 4)	106( 4)	62( 9)	<37	<46	<46
3C111.0	Fig. 8	242( 6)		461( 24)	577( 27)	741( 26)	876( 31)
3C120.0	Fig. 8	783( 8)		1145( 20)	634( 9)	465( 13)	439( 16)
3C123.0	Fig. 14	22( 2)	10( 3)	<32			
3C153.0	Fig. 14	<8	<10	<20			
3C171.0	Fig. 11	13( 4)	<15	<34			
3C173.1	Fig. 14	<10	13( 4)	<30			
3C192.0	Fig. 13	28( 4)	33( 4)	<24			
3C200.0	Fig. 14	<7	12( 3)	<18			
3C219.0	Fig. 10	<11	<12	<29			
3C234.0	Fig. 11		87( 4)	46( 13)	<40	<47	<38
3C236.0	Fig. 15	55( 5)	90( 2)	120( 9)	92( 13)	81( 15)	78( 14)
3C249.1	Fig. 9	64( 3)	62( 3)	45( 6)	<39	<46	<31
3C268.3	Fig. 10	22( 3)	32( 4)	<26			
3C273.0	Fig. 8				475( 16)	683( 11)	1062( 20)
3C274.1	Fig. 13	<6	<10	<19			
3C285.0	Fig. 12	222( 4)	292( 5)	307( 11)	180( 20)	74( 13)	<44
3C300.0	Fig. 13	<6	<8	<19			
3C305.0	Fig. 12		381( 4)	502( 9)	254( 22)	118( 17)	<64
3C310.0	Fig. 15		23( 1)	38( 3)	<30	<43	<41
3C315.0	Fig. 13		31( 3)	36( 9)	<24	<27	<27
3C319.0	Fig. 14	<7	<11	31( 8)			
3C321.0	Fig. 11				287( 16)	108( 13)	<40
3C326.0	Fig. 15	6( 2)	15( 1)	19( 4)	<30	<20	<23
3C341.0	Fig. 11	28( 3)	<11	<23			
3C349.0	Fig. 12	<11	<12	<23			
3C351.0	Fig. 9	172( 3)	156( 4)	89( 10)	<60	<81	<34
3C381.0	Fig. 10	35( 4)	34( 5)	39( 10)			
3C382.0	Fig. 8	76( 4)	96( 4)	97( 11)			
3C386.0	Fig. 15		66( 3)	81( 9)	<90	<43	<43
3C388.0	Fig. 15	<7	<9	<16			
3C390.3	Fig. 10	157( 4)	110( 4)	51( 8)			
3C401.0	Fig. 14	<8	<9	<18			
3C424.0	Fig. 14		7( 1)	<13	<22	<39	<28
3C433.0	Fig. 11	294( 4)	288( 2)	226( 6)	120( 22)	<51	<46
3C436.0	Fig. 13	16( 3)	30( 2)	37( 5)	<51	<30	<40
3C438.0	Fig. 14	<7	<11	<42			
3C452.0	Fig. 12	38( 4)	36( 5)	27( 8)			
3C459.0	Fig. 10		584( 4)	549( 11)	284( 15)	115( 11)	54( 16)



### 3.2. ISOCAM and Spitzer

We combined the SEDs in the MIR with data from the *Infrared Space Observatory* (Kessler *et al.* 1996) and *Spitzer Space Telescope* (Werner *et al.* 2004). We used photometric imaging observations with ISOCAM (Cesarsky *et al.* 1996) by Siebenmorgen *et al.* (2004) and spectra taken with the Infrared Spectrograph (IRS, Houck *et al.* 2004) from 5.2 to 38  $\mu\text{m}$ , which were extracted by the CASSIS (Lebouteiller *et al.* 2011) and newly stitched and scaled by the IDEOS project (Spoon 2012). From previous analysis of the spectra (Ogle *et al.* 2006) flux densities at 7 and 15  $\mu\text{m}$  restframe are included. Also photometric Spitzer data from the Multiband Imaging Photometer (MIPS, Rieke *et al.* 2004) at 24  $\mu\text{m}$  are used (Shi *et al.* 2005; Cleary *et al.* 2007; Hardcastle *et al.* 2009; Fu and Stockton 2009; Dicken *et al.* 2010; Shang *et al.* 2011).

### 3.3. 2MASS and WISE

We queried the *wise\_allwise\_p3as\_psd* data release from the Wide-field Infrared Survey Explorer (WISE, Wright *et al.* 2010) with the IDL *query\_irsacat* routine around 4" of the estimated positions for the 3CR sources. The allwise query delivers point source photometry in the 4 WISE bands (*W1/W2/W3/W4* at 3.4/4.6/12/22  $\mu\text{m}$ ) and also the point source photometry from the 2MASS catalogue for *J*, *H* and *K* filters at 1.235, 1.662 and 2.159  $\mu\text{m}$ .

Among the low-redshift sample six sources are extended, therefore PSF photometry was replaced by extended apertures<sup>5</sup> for 3C 31, 3C 35, 3C 98, 3C 120, 3C 236 and 3C 390. 2MASS photometry for extended sources<sup>6</sup> was delivered by querying *fp\_xsc* catalogue with the IDL *query\_irsacat* routine.

### 3.4. Visible wavelengths

A query on the SDSS catalogue (V/139/sdds9) with the IDL *query\_vizier* routine was performed. As not all sources were observed in SDSS, we complete the SEDs with data from Laing *et al.* (1983) and Véron-Cetty and Véron (2010). From the Hubble Space Telescope (HST) snapshot survey the host contribution in the visible was estimated

by taking encircled energy diagrams (EEDs) from Lehnert *et al.* (1999). Emission line data for [O II] and [O III] were collected from Grimes *et al.* (2004) and Jackson and Rawlings (1997). For the medium-redshift sample [O III] was measured for only 5 objects (3C 207, 3C 254, 3C 263, 3C 265 and 3C 334).

### 3.5. Radio wavelengths

At radio wavelengths the data were collected from NED, which gives reference to the following papers: Pilkington and Scott (1965); Pauliny-Toth *et al.* (1966); Gower *et al.* (1967); Aslanian *et al.* (1968); Kellermann *et al.* (1969); Colla *et al.* (1970); Stull (1971); Colla *et al.* (1972); Kellermann and Pauliny-Toth (1973); Fanti *et al.* (1974); Laing and Peacock (1980); Kuehr *et al.* (1981); Large *et al.* (1981); Geldzahler and Kuhr (1983); Ficarra *et al.* (1985); Baldwin *et al.* (1985); Hales *et al.* (1988, 1990); Becker *et al.* (1991); Gregory and Condon (1991); Hales *et al.* (1991); Becker *et al.* (1995); Waldram *et al.* (1996); Wren *et al.* (1992); Hales *et al.* (1993); Gear *et al.* (1994); Hales *et al.* (1995); Griffith *et al.* (1995); Klein *et al.* (1996); Rengelink *et al.* (1997); Condon *et al.* (1998); Bennett *et al.* (2003); Gilbert *et al.* (2004); Mack *et al.* (2005); Kassim *et al.* (2007); Cohen *et al.* (2007); Mantovani *et al.* (2009); Wright *et al.* (2009); Chen and Wright (2009); Chynoweth *et al.* (2009); Jenness *et al.* (2010); Agudo *et al.* (2010); Richards *et al.* (2011); Gold *et al.* (2011); Algaba *et al.* (2011); Lister *et al.* (2011)

## 4. Spectral Energy Distributions

Figures 1 to 7 show the rest-frame SEDs for the sample at  $0.5 < z < 1$ , separated for the AGN types with flat and steep radio spectrum (FSQ and SSQ), HERGs with strong, medium and faint MIR emission, one LERG and the 2 sources omitted from the analysis.

Figures 8 to 15 show the rest frame SEDs, separated for the FSQ and SSQ sources, BLRGs, HERGs and LERGs, that are seen at redshifts  $z < 0.5$ . The striking feature of the Herschel PACS/SPIRE data is that they nicely bridge the former gap between the radio and MIR SEDs. Also the WISE data points expand the previous ISOCAM and Spitzer IRS/MIPS24 SED coverage. A steep radio spectrum source is roughly constant in a  $\nu F_\nu$  diagram, while a flat radio

<sup>5</sup>[http://wise2.ipac.caltech.edu/staff/jarrett/wise/ext\\_src.html](http://wise2.ipac.caltech.edu/staff/jarrett/wise/ext_src.html)

<sup>6</sup><http://tdc-www.harvard.edu/catalogs/tmxsc.html>

source rises towards shorter wavelengths. For the host galaxy a synthetic stellar population from Bruzual and Charlot (2003) is used. The MIR emission is fitted with models for clumpy tori from Hönig and Kishimoto (2010). For the FIR a modified blackbody (Eq. 5) with emissivity index  $\beta = 1.5$  is used.

#### 4.1. SEDs at medium-redshifts

The quasar SEDs differ in their radio properties. 7 FSQs show a rise in their GHz spectra (e.g. 3C 207, Fig. 1), while the 7 SSQs have GHz spectra which are constant in  $\nu F_\nu$  (e.g. 3C 175, Fig. 2). A strong curvature is found in the MHz to GHz spectra of some CSS quasars and radio galaxies, (e.g. 3C 147 in Fig. 1, 3C 343 in Fig. 3 and 3C 343.1 in Fig. 4); some CSS with modest curvature are e.g. 3C 196 in Fig. 2, 3C 49 in Fig. 3 and 3C 455 in Fig. 4.

We group 3C 147 in the FSQs because of its SED rise between 90 GHz and 230 GHz (Steppe *et al.* 1995). The CSS 3C 455 and 3C 343 are sometimes classified as QSRs but they have neither a prominent 5 GHz core nor broad emission lines and therefore are treated here as HERGs (Figs. 3, 4).

The SSQs show a 1.5 dex thermal bump in MIR–FIR (Fig. 2). However, the FSQs show a  $\lesssim 0.5$  dex MIR–FIR emission bump above the extrapolated rising GHz spectrum. The FSQs most likely have a strong synchrotron contribution to their IR emission.

At optical wavelengths the quasars (FSQ and SSQ) show a strong power-law component rising towards shorter wavelengths. This component and the hot dust emission at about  $1 \mu\text{m}$  outshine the host galaxy. To estimate the host contribution in the SEDs we include the disentangled host galaxy magnitude from HST imaging by Lehnert *et al.* (1999) to guide a fit for the host galaxy.

Similarly to the SSQs, the HERGs (except 3C 268.1, Fig. 5) show a clear MIR–FIR emission component above the extrapolation of the radio spectrum to shorter wavelengths. However, there is a large diversity in the MIR. Figures 3 through 5 show the HERGs with strong, medium and weak MIR emission relative to the host galaxy.

While in both SSQs and HERGs the MIR SED is well determined, the detection rate in the FIR (at rest frame 60–100  $\mu\text{m}$ ) is 17 detections out of a

sample of 28 sources. The sources with FIR detections are also bright in the MIR, and the SED declines longward of 40  $\mu\text{m}$ . Examples are 3C 147 in Fig. 1, 3C 263 in Fig. 2, and 3C 226 in Fig. 3. The only exception with a good detected FIR plateau beyond 40  $\mu\text{m}$  is 3C 55 in Fig. 3. The MIR-bright sources with FIR upper limits mostly show the SED decline longward of 40  $\mu\text{m}$ , e.g., 3C 254 in Fig. 2, 3C 22 in Fig. 2, and 3C 280 in Fig. 3. The remaining sources with FIR upper limits often allow for an SED plateau beyond 40  $\mu\text{m}$  (Figs. 4 and 5).

The SED of the LERG 3C 427.1 shows faint MIR (and FIR) emission (Fig. 6), corroborating the idea that LERGs are AGN with low accretion activity (Ogle *et al.* 2006).

#### 4.2. SEDs at low-redshift

The quasar/BLRG SEDs differ in their radio properties. Four flat spectrum sources show a rise in their GHz spectra (Fig. 8), while the 10 steep spectrum sources have GHz spectra which are constant in  $\nu F_\nu$  (Figs. 9 and 10). A strong curvature is found in the MHz to GHz spectra of two CSS quasars and BLRGs, (3C 48 in Fig. 9, and 3C 268.3 in Fig. 10).

The steep spectrum sources show a clear MIR–FIR emission component above the extrapolation of the radio spectrum to shorter wavelengths (Fig. 9). In contrast, the flat spectrum sources show a relatively modest MIR–FIR emission bump above the extrapolated rising GHz spectrum. They most likely have a strong synchrotron contribution to their IR SED. At optical wavelengths the quasars (2 of the 4 FSQs and 3 of the 4 SSQs) show a strong power-law component rising towards shorter wavelengths.

Similarly to the SSQs, the HERGs show a clear MIR–FIR emission component above the extrapolation of the radio spectrum to shorter wavelengths. However, there is a large diversity in the MIR. Figures 11 to 13 show the HERGs with strong, medium and weak MIR emission relative to the host galaxy.

While in both SSQs and HERGs the MIR SED is well determined, the detection rate in the FIR (at rest frame 60–100  $\mu\text{m}$ ) is 38/48. For the HERGs with strong and medium MIR emission the SED declines longward of about 30–40  $\mu\text{m}$ .

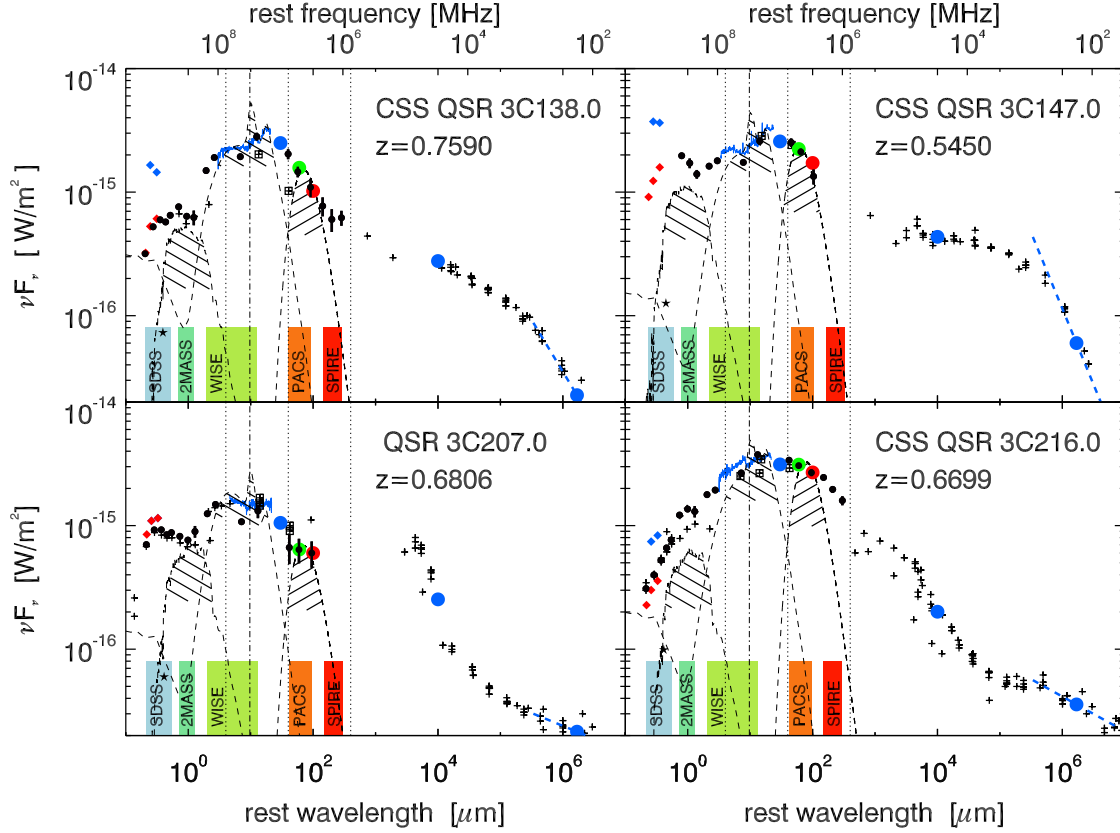


Fig. 1.— Spectral energy distributions of 4 flat spectrum quasars (FSQs) at  $0.5 < z < 1$ , i.e. quasars where the GHz respectively cm spectrum rises towards shorter wavelengths in  $\nu F_\nu$  scaling. Filled black circles with error bars denote detections,  $3\sigma$  upper limits are marked by arrows. The Herschel PACS and SPIRE band ranges are shadowed in red, the 2MASS and WISE ranges in green, the optical (SDSS) range in blue. Red and blue diamonds are optical photometry values from Véron-Cetty and Véron (2010) and from Laing *et al.* (1983), respectively. “+” symbols are detections (with arrows: upper limits) collected via NED. Disentangled host flux from Lehnert *et al.* (1999) is shown with a star symbol. Black open squares mark photometry with Spitzer/MIPS at  $24 \mu\text{m}$  or Spitzer/IRS; IRS spectra are plotted as blue lines and the position of the  $9.7 \mu\text{m}$  silicate absorption is indicated by the black vertical dash-dotted line. SCUBA 450/850  $\mu\text{m}$  and IRAM 1.2 mm data points by Haas *et al.* (2004) are marked with black dots. Large blue dots mark median data points at 30 GHz and 178 MHz restframe. Big blue, green and red dots at IR-wavelengths mark interpolated flux levels at 30, 60 and  $100 \mu\text{m}$ , respectively. Models of the host galaxy, the AGN heated warm dust and the SF heated cool dust are shown as dashed lines.

Fig. 1.— continued

Fig. 2.— Spectral energy distributions of 6 steep spectrum quasars (SSQs) at  $0.5 < z < 1$ , with strong optical AGN continuum and one BLRG without strong optical AGN continuum. Notation as in Fig.1.

Fig. 3.— Spectral energy distributions of high excitation radio galaxies (HERGs) at  $0.5 < z < 1$ , with bright MIR emission, up to a factor ten above the host galaxy level. Note the deep  $9.7 \mu\text{m}$  silicate absorption in the CSS 3C 49 and in 3C 55, 3C 226 and 3C 343. Notation as in Fig.1.

Fig. 4.— Spectral energy distributions of high excitation radio galaxies (HERGs) at  $0.5 < z < 1$ , with medium MIR emission, reaching at about  $30 \mu\text{m}$  the host galaxy level. Note the valley of low  $4 - 10 \mu\text{m}$  emission in most sources. 3C 330 and 3C 441 are the only sources with successfully measured  $9.7 \mu\text{m}$  silicate absorption. Notation as in Fig.1.

Fig. 5.— Spectral energy distributions of HERGs at  $0.5 < z < 1$ , with weak MIR emission. All sources have a low  $4 - 10 \mu\text{m}$  emission and barely reach at about  $30 \mu\text{m}$  the host galaxy level. Notation as in Fig.1.

Fig. 6.— Spectral energy distributions of the only LERG in our sample at  $0.5 < z < 1$ . Note the low MIR flux compared to the host flux. Notation as in Fig.1.

Fig. 7.— Spectral energy distributions of two HERGs at  $0.5 < z < 1$ , which have been excluded from the analysis. 3C 175.1 has too few data points and 3C 220.3 shows excess FIR-submm emission due to a gravitationally lensed submillimetre galaxy at  $z=2.2$  (Haas et al. 2014). Notation as in Fig.1.

Fig. 8.— Spectral energy distributions of the flat spectrum sources at  $z < 0.5$ , three BLRGs and one quasar. Notation as in Fig.1.

Fig. 9.— Spectral energy distributions of steep spectrum quasars at  $z < 0.5$ . Notation as in Fig.1.

Fig. 10.— Spectral energy distributions of steep spectrum BLRGs at  $z < 0.5$ . Notation as in Fig.1.

Fig. 11.— Spectral energy distributions of high excitation narrow line radio galaxies with strong MIR emission at  $z < 0.5$ . Notation as in Fig.1.

Fig. 12.— Spectral energy distributions of high excitation narrow line radio galaxies with medium MIR emission at  $z < 0.5$ . Notation as in Fig.1.

Fig. 13.— Spectral energy distributions of high excitation narrow line radio galaxies with weak MIR emission. Notation as in Fig.1.

Fig. 14.— Spectral energy distributions of low excitation narrow line radio galaxies (LERGS) at  $z < 0.5$ . Notation as in Fig.1.

Fig. 15.— Spectral energy distributions of LERGS, with very low  $L_{\text{MIR}}/L_{\text{Host}}$  at  $z < 0.5$ . Notation as in Fig.1.

The SEDs of the HERGs with weak MIR emission and of the LERGs show faint MIR emission but mostly a rise towards the FIR (Figs. 13 to 15).

#### 4.3. Median SEDs of Quasars and Radio-Galaxies

The SEDs of all sources were scaled to  $\nu L_\nu$  with their luminosity distance  $D_L$  given in Tables 1 and 2. The median SEDs were built for the classes FSQ, SSQ, BLRG, HERG and LERG for each redshift sample as given in Tables 7 and 8. The individual SEDs were first normalized to their 178 MHz rest frame flux density, which is interpolated and tabulated in Tables 16 and 17 and then scaled to the median luminosity of the sub-sample at 178 MHz. The scaled SEDs were combined in continuous bins of 100 consecutive data points. In each bin the median wavelength, luminosity and standard deviation in logarithmic space was calculated and plotted in Figure 16. The templates are tabulated in Table 6.

The 178 MHz restframe flux normalization was chosen because orientation effects can be excluded. Even so, the radio-lobe power may be influenced by the environment of the 3C sources. As shown in Section 5.3 there is a trend of the ratio of radio-to-MIR luminosities changes with redshift, which can be interpreted as a denser environment at earlier ages. Therefore separate templates are provided for a range of source types and redshift ranges.

While for HERGs, LERGs and also for BLRGs, the stellar component of the SEDs is visible and can be fitted well, for the SSQs and FSQs the strong power-law shaped AGN continuum in the optical and ultra-violet has to be taken into account. Because that was not possible in a consistent manner, the host galaxy fits and the derived stellar masses have to be seen as upper limits for the quasars (Section 4.4).

In the  $\nu L_\nu$  scaling both quasar types, FSQ and SSQ, show a flat, nearly identical distribution in the range from  $0.1 \mu\text{m} \lesssim \lambda \lesssim 20 \mu\text{m}$ , justifying the assumption that the two classes are intrinsically similar objects. At wavelengths beyond  $20 \mu\text{m}$  the median SED of FSQs and SSQs diverges with a flux higher in the FSQs. This was interpreted in the past as a jet component (Cleary *et al.* 2007) which is relativistically beamed towards us. Now with the new Herschel data included, the jet en-

hancement can be traced to FIR wavelengths for the FSQs, which also shows up in the non-thermal shape of the SED. FIR-inferred SFR rates have therefore only are upper limits for the FSQs (Section 4.4).

The HERGs and LERGs median SEDs appear quite differently at IR wavelength. On average the HERGs are one dex more luminous in the MIR than the LERGs. The weak MIR activity of LERGs was interpreted as low accretion activity (Ogle *et al.* 2006). For both types the MIR shows absorption features from silicate at  $9.7 \mu\text{m}$  absent in all quasar (FSQ, SSQ, BLRG) median SEDs. LERGs have a relatively weaker dust to starlight continuum ratio than HERGs. For LERGs the peak in the FIR is more distinguished and shifted to longer wavelengths, suggesting cooler dust compared to HERGs.

#### 4.4. Decomposition into Host, AGN Torus and Star formation

The components and structure of the galaxy (gas dust, stars, radio-jets and lobes) are reflected in the SEDs and can be disentangled from it. The stellar emission of the host galaxy peaks, depending on the stellar population, between NIR and UV wavelength (Fioc and Rocca-Volmerange 1997; Bruzual and Charlot 2003; De Breuck *et al.* 2010).

In the orientation-based unified scheme of powerful FR II radio galaxies and quasars (Barthel 1989; Antonucci 1993) the optical and UV emission of the central engine is blocked in some directions by anisotropically distributed dust. The heating by the AGN causes the warm dust emission to peak at restframe MIR ( $10\text{--}40 \mu\text{m}$ ) wavelength (Rowan-Robinson 1995), which has been observed for most of the 3C sources (e.g., Siebenmorgen *et al.* 2004; Ogle *et al.* 2006; Hardcastle *et al.* 2009). A torodial and clumpy configuration in the so called dust torus is a widely accepted hypothesis for the dust configuration (Nenkova *et al.* 2002; Hönig *et al.* 2006; Siebenmorgen *et al.* 2015).

The dust-enshrouded formation of stars causes the stellar light to be reprocessed by the dust. Corresponding to the cool temperature the re-emission peaks at  $\sim 100 \mu\text{m}$  (Schweitzer *et al.* 2006; Netzer *et al.* 2007; Veilleux *et al.* 2009).

Table 6: Median spectral templates for different galaxy types separated for low- ( $z < 0.5$ ) and medium-redshift ( $0.5 < z < 1$ ).

	HERG-low-z	HERG-med-z	LERG	BLRG	FSQ-low-z	FSQ-med-z	SSQ-low-z	SSQ-med-z
$\log(\lambda_{Rest})$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$	$\log(\nu L_\nu)$
$[\mu m]$	$[L_\odot]$	$[L_\odot]$	$[L_\odot]$	$[L_\odot]$	$[L_\odot]$	$[L_\odot]$	$[L_\odot]$	$[L_\odot]$
-0.4	$10.4 \pm 0.7$	$10.7 \pm 0.4$				$11.8 \pm 0.3$		$12.0 \pm 0.6$
-0.3	$10.7 \pm 0.7$	$11.0 \pm 0.3$	$10.6 \pm 1.0$	$10.7 \pm 0.5$	$11.0 \pm 0.4$	$11.8 \pm 0.2$	$11.6 \pm 1.0$	$12.0 \pm 0.6$
-0.2	$11.0 \pm 0.7$	$11.1 \pm 0.3$	$10.8 \pm 0.9$	$10.9 \pm 0.5$	$10.9 \pm 0.3$	$11.8 \pm 0.2$	$11.6 \pm 1.0$	$12.0 \pm 0.6$
-0.1	$10.9 \pm 0.7$	$11.1 \pm 0.3$	$11.0 \pm 0.9$	$11.0 \pm 0.4$	$10.9 \pm 0.3$	$11.8 \pm 0.2$	$11.6 \pm 1.1$	$12.0 \pm 0.4$
-0.0	$11.0 \pm 0.6$	$11.1 \pm 0.2$	$11.0 \pm 0.9$	$11.0 \pm 0.4$	$10.9 \pm 0.3$	$11.8 \pm 0.2$	$11.6 \pm 1.2$	$12.0 \pm 0.4$
0.1	$11.1 \pm 0.5$	$11.1 \pm 0.2$	$11.2 \pm 0.9$	$11.0 \pm 0.3$	$10.8 \pm 0.4$	$11.8 \pm 0.2$	$11.7 \pm 1.2$	$12.0 \pm 0.4$
0.2	$11.0 \pm 0.5$	$11.1 \pm 0.2$	$11.1 \pm 0.9$	$11.1 \pm 0.3$	$10.9 \pm 0.5$	$11.8 \pm 0.2$	$11.7 \pm 1.2$	$12.0 \pm 0.4$
0.3	$10.9 \pm 0.5$	$11.1 \pm 0.2$	$11.1 \pm 1.0$	$11.1 \pm 0.3$	$11.0 \pm 0.4$	$11.8 \pm 0.2$	$11.7 \pm 1.0$	$12.0 \pm 0.4$
0.4	$10.9 \pm 0.5$	$11.2 \pm 0.2$	$10.5 \pm 1.2$	$11.1 \pm 0.3$	$11.0 \pm 0.5$	$11.8 \pm 0.2$	$11.7 \pm 1.0$	$12.0 \pm 0.3$
0.5	$10.7 \pm 0.5$	$11.3 \pm 0.3$	$10.3 \pm 1.3$	$11.1 \pm 0.4$	$11.0 \pm 0.4$	$11.9 \pm 0.2$	$11.7 \pm 1.0$	$12.2 \pm 0.3$
0.6	$10.6 \pm 0.5$	$11.4 \pm 0.3$	$9.9 \pm 1.3$	$11.1 \pm 0.4$	$10.9 \pm 0.4$	$11.9 \pm 0.2$	$11.7 \pm 0.2$	$12.0 \pm 0.2$
0.7	$10.6 \pm 0.5$	$11.3 \pm 0.3$	$9.5 \pm 0.9$	$11.0 \pm 0.5$	$10.9 \pm 0.4$	$11.9 \pm 0.2$	$11.8 \pm 0.2$	$12.2 \pm 0.3$
0.8	$10.7 \pm 0.6$	$11.5 \pm 0.3$	$9.6 \pm 0.9$	$11.3 \pm 0.5$	$11.0 \pm 0.4$	$12.0 \pm 0.2$	$11.9 \pm 0.2$	$12.1 \pm 0.3$
0.9	$10.7 \pm 0.7$	$11.4 \pm 0.3$	$9.4 \pm 0.8$	$11.0 \pm 0.5$	$10.9 \pm 0.4$	$12.0 \pm 0.2$	$11.9 \pm 1.6$	$12.0 \pm 0.3$
1.0	$10.8 \pm 0.7$	$11.3 \pm 0.3$	$9.4 \pm 0.7$	$11.3 \pm 0.5$	$10.9 \pm 0.4$	$12.0 \pm 0.2$	$12.0 \pm 1.5$	$12.1 \pm 0.3$
1.1	$10.8 \pm 0.7$	$11.3 \pm 0.3$	$9.6 \pm 0.7$	$11.5 \pm 0.5$	$10.8 \pm 0.5$	$12.1 \pm 0.2$	$11.7 \pm 0.2$	$12.1 \pm 0.4$
1.2	$10.9 \pm 0.7$	$11.4 \pm 0.4$	$9.8 \pm 0.6$	$11.5 \pm 0.4$	$10.7 \pm 0.5$	$12.1 \pm 0.2$	$12.1 \pm 0.2$	$12.2 \pm 0.4$
1.3	$10.9 \pm 0.7$	$11.4 \pm 0.3$	$9.8 \pm 0.5$	$11.5 \pm 0.5$	$10.7 \pm 0.5$	$12.0 \pm 0.2$	$12.1 \pm 0.3$	$12.4 \pm 0.3$
1.4	$10.8 \pm 0.7$	$11.3 \pm 0.5$	$9.5 \pm 0.5$	$11.4 \pm 0.5$	$10.6 \pm 0.6$	$12.0 \pm 0.2$	$12.2 \pm 0.4$	$12.5 \pm 0.5$
1.5	$10.8 \pm 0.7$	$11.3 \pm 0.5$	$10.6 \pm 0.8$	$11.3 \pm 0.5$	$10.5 \pm 0.7$	$11.9 \pm 0.2$	$12.1 \pm 0.4$	$12.5 \pm 0.5$
1.6	$10.8 \pm 0.7$	$11.3 \pm 0.5$	$10.7 \pm 0.9$	$11.3 \pm 0.5$	$10.4 \pm 0.8$	$11.9 \pm 0.3$	$12.1 \pm 0.4$	$12.2 \pm 0.7$
1.7	$10.8 \pm 0.7$	$11.2 \pm 0.6$	$10.6 \pm 0.9$	$11.3 \pm 0.5$	$10.3 \pm 0.8$	$11.8 \pm 0.3$	$11.9 \pm 0.6$	$11.6 \pm 0.8$
1.8	$10.5 \pm 0.7$	$11.0 \pm 0.7$	$10.4 \pm 0.9$	$11.2 \pm 0.7$	$10.2 \pm 0.8$	$11.8 \pm 0.3$	$11.8 \pm 0.9$	$11.4 \pm 0.8$
1.9	$10.3 \pm 0.8$	$11.0 \pm 0.7$	$10.0 \pm 0.9$	$11.0 \pm 0.8$	$10.3 \pm 0.8$	$11.7 \pm 0.3$	$11.7 \pm 1.0$	$11.3 \pm 0.8$
2.0	$10.2 \pm 0.9$	$10.9 \pm 0.7$	$9.8 \pm 0.9$	$10.7 \pm 0.9$	$10.3 \pm 0.8$	$11.7 \pm 0.3$	$11.6 \pm 1.0$	$10.9 \pm 0.8$
2.1	$10.1 \pm 1.0$	$10.8 \pm 0.6$	$9.7 \pm 0.9$	$10.5 \pm 0.9$	$10.2 \pm 0.7$	$11.6 \pm 0.3$	$11.3 \pm 1.0$	$10.9 \pm 0.8$
2.2	$9.9 \pm 1.0$	$10.8 \pm 0.6$	$9.5 \pm 1.0$	$10.1 \pm 0.8$	$10.2 \pm 0.7$	$11.6 \pm 0.3$	$11.1 \pm 1.0$	$10.9 \pm 0.8$
2.3	$9.7 \pm 1.0$	$10.8 \pm 0.6$	$9.5 \pm 0.9$	$9.9 \pm 0.8$	$10.2 \pm 0.7$	$11.6 \pm 0.3$	$11.0 \pm 1.0$	$10.9 \pm 0.8$
2.4	$9.6 \pm 0.9$	$10.8 \pm 0.6$	$9.3 \pm 0.9$	$9.8 \pm 0.8$	$10.2 \pm 0.7$	$11.6 \pm 0.3$	$10.9 \pm 1.0$	$10.9 \pm 0.8$
2.5	$9.5 \pm 0.9$	$10.8 \pm 0.6$	$9.2 \pm 0.9$	$9.8 \pm 0.8$	$10.2 \pm 0.6$	$11.6 \pm 0.3$	$10.7 \pm 1.0$	$10.9 \pm 0.8$
3.0	$9.4 \pm 0.9$	$10.6 \pm 0.6$	$9.2 \pm 0.9$	$9.8 \pm 0.8$	$10.1 \pm 0.6$	$11.6 \pm 0.3$	$10.3 \pm 1.0$	$10.9 \pm 0.8$
3.4	$9.4 \pm 0.9$	$10.6 \pm 0.6$	$9.2 \pm 0.9$	$9.8 \pm 0.8$	$10.0 \pm 0.5$	$11.4 \pm 0.2$	$10.3 \pm 1.0$	$10.8 \pm 0.8$
3.8	$9.3 \pm 0.7$	$10.6 \pm 0.6$	$9.2 \pm 0.9$	$9.8 \pm 0.8$	$9.8 \pm 0.4$	$11.2 \pm 0.3$	$10.3 \pm 1.0$	$10.7 \pm 0.8$
4.2	$9.1 \pm 0.6$	$10.4 \pm 0.6$	$9.2 \pm 0.8$	$9.7 \pm 0.7$	$9.6 \pm 0.4$	$11.1 \pm 0.3$	$10.3 \pm 0.9$	$10.6 \pm 0.7$
4.6	$9.0 \pm 0.4$	$10.4 \pm 0.3$	$9.1 \pm 0.4$	$9.6 \pm 0.3$	$9.3 \pm 0.5$	$11.0 \pm 0.3$	$10.2 \pm 0.8$	$10.6 \pm 0.2$
5.0	$9.0 \pm 0.1$	$10.4 \pm 0.3$	$9.1 \pm 0.3$	$9.4 \pm 0.1$	$8.8 \pm 0.5$	$10.8 \pm 0.3$		$10.5 \pm 0.2$
5.4	$9.0 \pm 0.2$	$10.3 \pm 0.2$	$9.0 \pm 0.1$	$9.4 \pm 0.1$	$8.4 \pm 0.4$	$10.5 \pm 0.2$		$10.4 \pm 0.1$
5.8	$8.9 \pm 0.2$	$10.2 \pm 0.2$	$8.9 \pm 0.2$	$9.3 \pm 0.1$		$10.4 \pm 0.2$		$10.4 \pm 0.1$
6.2	$8.8 \pm 0.1$	$10.1 \pm 0.1$	$8.8 \pm 0.1$	$9.2 \pm 0.2$		$10.2 \pm 0.2$		$10.4 \pm 0.1$
6.6	$8.7 \pm 0.1$	$10.0 \pm 0.2$	$8.7 \pm 0.1$	$9.1 \pm 0.1$				$10.3 \pm 0.1$

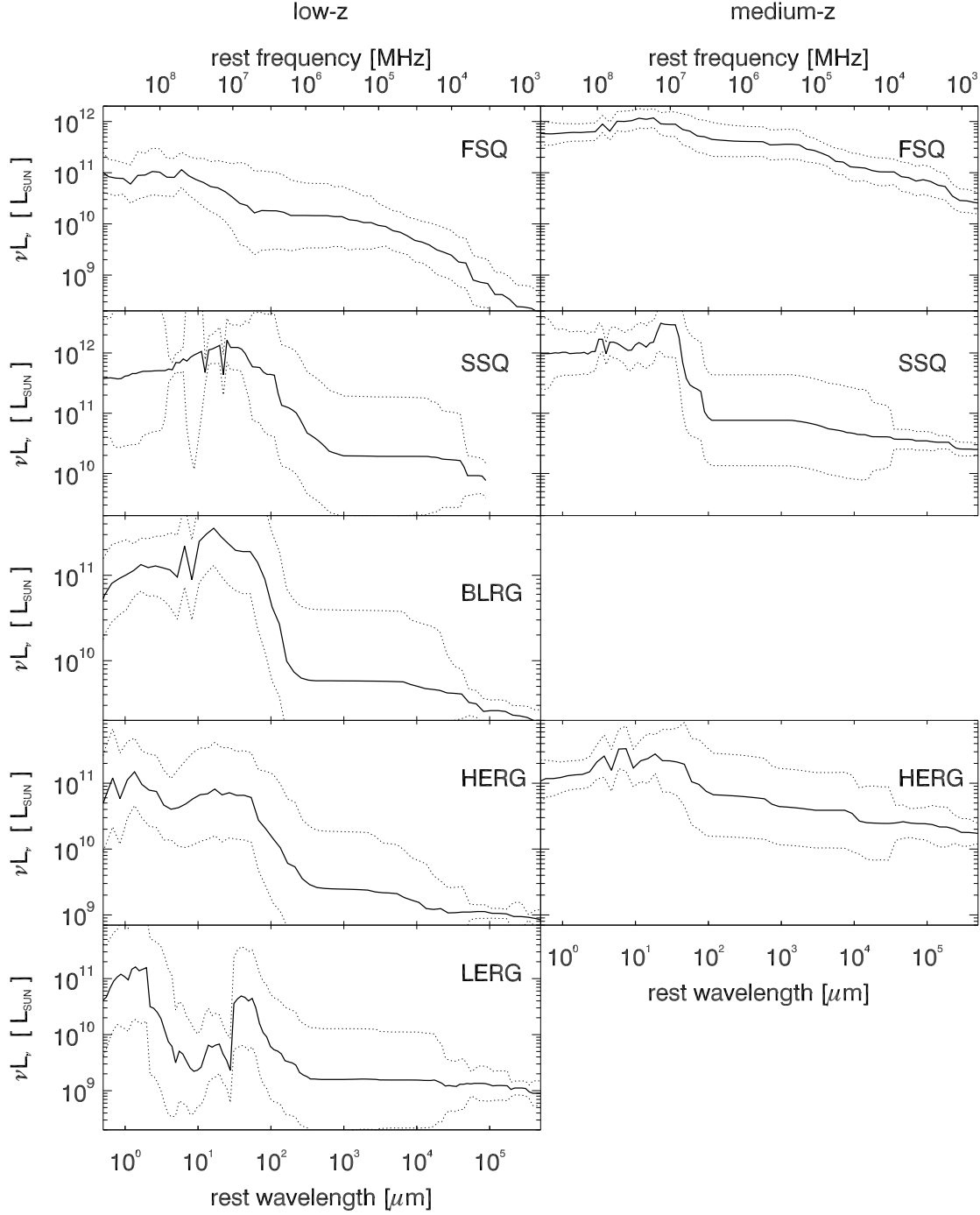


Fig. 16.— Median of individual SEDs first normalized to their 178MHz rest frame flux and then scaled to the median luminosity of each sub-sample (see Tables 7 and 8) at 178MHz, this normalization may be influenced by the source environment.

The aim of the analysis is to quantify host galaxy stellar mass and star formation rates in the environment of the strong AGN emission, which can contribute at all wavelength ranges. Also the question of the unification of radio galaxies and quasars shall be answered at the FIR wavelengths, where the opacity is low. From the SEDs are extracted:

a)  $L_{\text{Host}}$ , the luminosity of the stars in the host galaxy, by integration over fitted synthetic stellar population models by Bruzual and Charlot (2003) (libraries available from Mariska Kriek<sup>7</sup>). From the synthetic stellar population templates the luminosity of the stars in the host galaxy  $L_{\text{Host}}$  (Eq. 2) was derived. With the inherent mass-to-light ratio  $(\frac{M}{L})_{\text{BC03}}$  of the templates, stellar masses  $M_{\star}$  can then be calculated (Eq. 3). Values for both samples are given in Tables 10 and 11. The templates were calculated with an exponentially declining star formation history (with time scale  $\nu$  [log yr]), metallicities  $Z$  ranging from sub- to super-solar, and a Chabrier IMF. Free parameters in the fitting routine were  $\nu$ ,  $Z$ , and the age of the stellar population. The synthesized flux-densities  $F_{\lambda}^0$  were attenuated for the extinction in the interstellar medium with the dust-attenuation  $k(\lambda)$  and  $R_V = 4.05$  (Calzetti *et al.* 2000, see Eq. 1). The dependence of the derived stellar masses on the extinction coefficient  $A_V$  is weak for a sample of early type galaxies (see Swindle *et al.* 2011). Therefore the median  $A_V = 0.1$  found for the Swindle *et al.* (2011) sample was applied here.

$$F_{\lambda}^{\text{att}} = F_{\lambda}^0 \cdot 10^{-0.4A_V k(\lambda)/R_V} \quad (1)$$

$$L_{\text{Host}} = 4\pi D_L^2 \int F_{\nu}^{\text{BC03}} d\nu \quad (2)$$

$$M_{\star} = \left(\frac{M}{L}\right)_{\text{BC03}} \times L_{\text{Host}} \quad (3)$$

b)  $L_{\text{AGN}}$ , the luminosity of the AGN powered dust (torus), by integration over fitted torus models by Hönig and Kishimoto 2010. The MIR emission was fitted using a template library<sup>8</sup>. Parameters of the best fitting template with the derived total luminosity  $L_{\text{AGN}}$  (Eq. 4) are given in Tables

12 and 13. Parameters used for the fitting process were: The index  $a$  of the power law for radial dust cloud distribution, the number  $N$  of clouds along the equatorial line of sight, the half opening angle  $\theta$ , the optical depth  $\tau$  and the inclination to the observer  $i$ .

$$L_{\text{AGN}} = 4\pi D_L^2 \int F_{\nu}^{\text{HK10}} d\nu \quad (4)$$

c)  $L_{\text{FIR}}$ , the luminosity of cool FIR emitting dust, by integration of a modified blackbody at 20–50 K ( $\beta = 1.5$ ), which is given by

$$F_{\nu}^{\text{MBB}} \propto \nu^{\beta} B_{\nu}(T_D) \quad (5)$$

and

$$L_{\text{FIR}} = 4\pi D_L^2 \int F_{\nu}^{\text{MBB}} d\nu \quad (6)$$

The FIR emission can be attributed to dust heated by stars. The integrated luminosity  $L_{\text{FIR}}$  was used to estimate the SFR by applying Eq. 7 (taken from Kennicutt 1998 Eq. (4)), which is valid for starbursts with an age less than  $10^8$  years. Values are given in Tables 14 and 15.

$$\text{SFR} \left[ \frac{M_{\odot}}{\text{yr}} \right] = 4.5 \times 10^{-44} L_{\text{FIR}} \left[ \frac{\text{erg}}{\text{s}} \right] \quad (7)$$

d) Monochromatic luminosities at rest frame  $\nu L_{\nu}^{30 \text{ GHz}}$ ,  $\nu L_{\nu}^{178 \text{ MHz}}$  were used to trace synchrotron contribution from radio jets and inclination effects in the IR at  $\nu L_{\nu}^{30 \mu\text{m}}$ ,  $\nu L_{\nu}^{60 \mu\text{m}}$ ,  $\nu L_{\nu}^{100 \mu\text{m}}$  from interpolated fluxes (Tables 16 and 17).

Present AGN torus models often require an ad hoc  $T = 1300$  K (Leipski *et al.* 2013; Podigachoski *et al.* 2015a) dust component in quasars to fit the near-infrared (NIR) bump around  $3 \mu\text{m}$ . In addition, new AGN torus models (Siebenmorgen *et al.* 2015) invoke fluffy dust particles and are able to fit the AGN SEDs to longer wavelengths compared to the HK models, with SED peak beyond  $\sim 80 \mu\text{m}$ . This increases the ambiguity of AGN-SF model fitting and star formation may be even lower than indicated by our analysis here.

#### 4.5. Bayesian SED fitting

The fitting of all components was achieved by the application of a Metropolis-Hastings algorithm

<sup>7</sup>[http://astro.berkeley.edu/~mariska/FAST\\_Download.html](http://astro.berkeley.edu/~mariska/FAST_Download.html)

<sup>8</sup><http://www.sungazer.org/CAT3D.html>



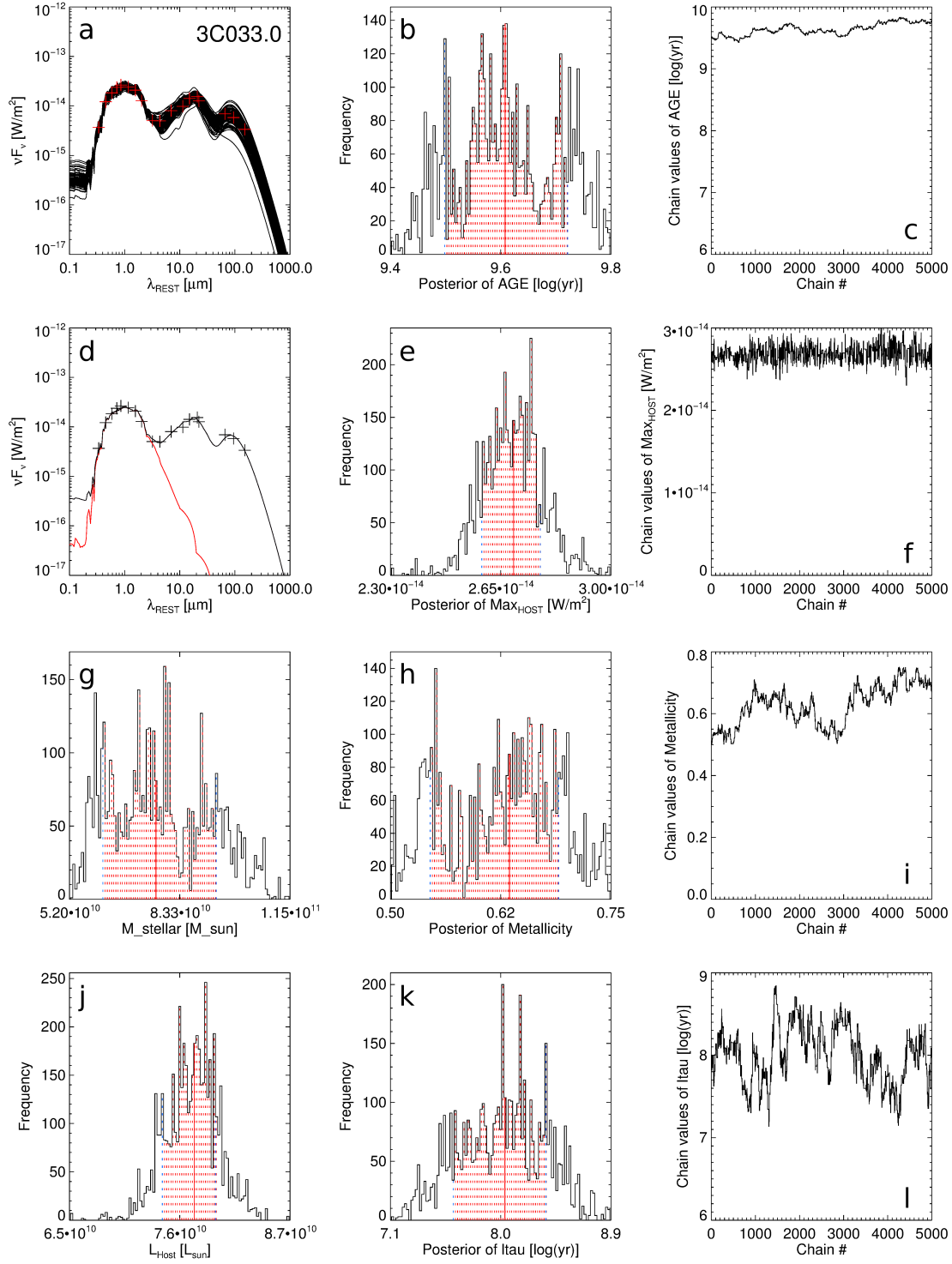


Fig. 17.— Host fit: a) SED with black lines: range of considered models; d) SED with red line: best host template, black line: sum of best templates; b,e,g,h,j,k) distributions of host parameters and derived quantities, red solid line: median of distribution, red shaded area: 16%–84% interval of the total frequency; c,f,i,l) Monte-Carlo chains of host parameters.

Fig. 18.— Torus fit: a) SED with red line: best torus template, black line: sum of best templates; b,d,e,g,h,j,k) distributions of torus parameters and derived quantities, red solid line: median of distribution, red shaded area: 16%–84% interval of the total frequency; c,f,i,l) Monte-Carlo chains of torus parameters.

Fig. 19.— FIR fit: a) SED with red line: best FIR template, black line: sum of best templates; b,d,e) distributions of FIR parameters and derived quantities, red solid line: median of distribution, red shaded area: 16%–84% interval of the total frequency; c,f) Monte-Carlo chains of FIR parameters.

under the investigation of the posterior probability  $Post(M|D)$  of the model  $M$  fitting the data  $D$ , which can be written after Baye's theorem (Eq. 8) with the prior of the model  $Prior(M)$  and data  $Prior(D)$  and the likelihood of the data given the model  $Like(D|M)$ .

$$Post(M|D) = \frac{Like(D|M)Prior(M)}{Prior(D)} \quad (8)$$

The prior  $Prior(p)$  of a single model parameter  $p$  in the range of the maximum and minimum allowed values  $p_{max}$  and  $p_{min}$  is given by the probability density of the uniform distribution (Eq. 9).

$$Prior(p) = \frac{1}{p_{max} - p_{min}} \quad (9)$$

Then the prior  $Prior(M)$  of the whole model can be written in logarithmic space as Eq. 10.

$$Prior(M) = \sum_i \ln Prior(p_i) \quad (10)$$

The likelihood  $Like(d|m)$  of single model point  $m$  fitting a data point  $d$  with mean value  $\mu$  and standard deviation  $\sigma$  is given by the probability density of the normal distribution (Eq. 11).

$$Like(d|m) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(m-\mu)^2}{2\sigma^2}} \quad (11)$$

The likelihood  $Like(D|M)$  of the whole model  $M$  fitting the data  $D$  can then be written like Eq. 12.

$$Like(D|M) = \sum_i \ln Like(d_i|m_i) \quad (12)$$

With this nomenclature, a constant  $Prior(D)$  and using the logarithmic metric the posterior probability is calculated like Eq. 13.

$$Post(M|D) = Like(D|M) + Prior(M) \quad (13)$$

Modelling parameters and ranges for host, torus and FIR templates are given in Table 9. The Metropolis-Hastings Monte-Carlo chain starts for each source with an individual set of scaling factors for host-, torus- and FIR-template, while  $Metal_{start} = 0.5$ ,  $v_{start} = 10^7$ ,  $Age_{start} = 10^{9.5}$  for the host  $N_{start} = 5.0$ ,  $a_{start} = -1$ ,  $\theta_{start} = 32.5$  and  $\tau_{start} = 35$  for the torus were selected equally for all sources. The start value for inclination was set to  $5^\circ$  for type 1 sources and  $45^\circ$  for type 2 sources. The start value for  $T_{FIR}$  was also selected individually for each source. The Metropolis-Hastings algorithm proceeds by randomizing the model parameters  $M_i$  of the preceding iteration with a proposal function  $M_{i+1} = func\_proposal(M_i)$  which was tuned to allow the chain values to vary in suitable steps for each model parameter. Then the posterior probability of the preceding model set  $Post(M_i|D)$  was compared and normalized to the new proposed model set  $Post(M_{i+1}|D)$  and the probability of an improvement was computed via Eq. 14

$$Prob(M_i|M_{i+1}|D) = e^{Post(M_{i+1}|D) - Post(M_i|D)} \quad (14)$$

The computed value of  $Prob(M_i|M_{i+1}|D)$  was compared to a uniformly distributed random number between 0 and 1. If  $Prob(M_i|M_{i+1}|D)$  was greater than this random number the proposed model set  $M_{i+1}$  was included in the Monte-Carlo chain and chosen as new start value for the next iteration step. This procedure allows the chain to evolve to better models while also models which don't seem to be an actual improvement retain a small chance to enter the chain. By this behaviour the Metropolis-Hastings algorithm is able

to leave local maxima in the posterior space and search for the global one. For each model 10000 chain values were calculated and the last 5000 iterations were used for the analysis via histograms for each model parameter (see Figures 17, 18 and 19).

## 5. Results and discussion

### 5.1. MIR-weak sources

Based on 15  $\mu\text{m}$  luminosity measured in the Spitzer IRS spectra, Ogle *et al.* (2006) defined MIR-weak sources by an absolute monochromatic threshold,  $\nu L_\nu^{15\ \mu\text{m}} < 8 \cdot 10^{43} \text{erg/s}$  (roughly corresponding to the integrated luminosity of the torus model fit of  $L_{\text{MIR}} = 2 \cdot 10^{10} L_\odot$ ). While successfully identifying MIR-weak sources at low-redshift, potential analogs at higher redshift may be missed because they fall below the detection limit, and a more flexible definition is desired – also because  $F_\nu^{15\ \mu\text{m}}$  is not available for all of our sources. The torus and host template fits are able to measure the entire integrated MIR luminosity as well as the host luminosity. Therefore we define MIR-weak sources relative to the host galaxy:  $L_{\text{MIR}}/L_{\text{Host}} < 1$  (Fig. 20). By this threshold all galaxies classified as LERGs are included in the MIR-weak definition, as well as some sources classified by their optical spectra as HERGs. Also two MIR-weak BLRGs, 3C 219 and 3C 382 are found according to this definition.

For 3C 219 (see Fig. 10) the MIR-weakness can be verified from the SED, where the fits of host and torus agree well with the observed data. For the flat-spectrum BLRG 3C 382, the host luminosity cannot be independently estimated, and the model fit is most likely an over-estimate as contamination from the AGN could not be disentangled. A weaker ratio of  $L_{\text{MIR}}/L_{\text{Host}} < \frac{1}{3}$  is also indicated in Fig. 20 which would exclude the two BLRGs but also two LERGs and several HERGs from the MIR-weak definition.

The definition is motivated by the relation of black-hole and bulge masses ((Häring and Rix 2004)), thus more massive galaxies can reach a larger accretion luminosity. To check the consistency of the inferred host masses and MIR luminosities, the black hole masses  $M_{\text{BH}}$  have been calculated with Eq. 15 taken from Häring and Rix (2004) with stellar mass estimates  $M_\star$  derived

from the host luminosities  $L_{\text{Host}}$  as input (see Tables 10 and 11). We find black hole masses in the range of  $\approx 10^6 - 10^9 M_\odot$  consistent with the range found for example by Tremaine *et al.* (2002)

$$\log(M_{\text{BH}}/M_\odot) = (8.2 \pm 0.1) + (1.12 \pm 0.06) \times \log(M_{\text{Bulge}}/10^{11} M_\odot) \quad (15)$$

With the derived black hole masses  $M_{\text{BH}}$  we are able to calculate the limiting Eddington luminosity  $L_{\text{Edd}}$  as Eq. 16. The ratio of AGN luminosity in the MIR and Eddington luminosity  $L_{\text{AGN}}/L_{\text{Edd}}$  is given in Tables 12 and 13. The comparison shows an average ratio of a few percent with none of the sources exceeding the Eddington limit.

$$L_{\text{Edd}} \approx 3.2 \times 10^4 \left( \frac{M_{\text{BH}}}{M_\odot} \right) L_\odot \quad (16)$$

The definition of MIR-weak sources relative to the hosts has the advantage that it is independent of absolute luminosities and thus may allow us to identify MIR-weak sources also at higher redshift. (In fact, we find MIR-weak sources which exceed Ogle *et al.*'s absolute luminosity limit by about a factor of ten). In the plots, MIR-weak sources are marked with a superposed "x".

Beyond  $z > 0.5$ , the 3C-sample contains 5 MIR-weak HERGs but only one LERG 3C 427.1 ( $L_{\text{MIR}}$  upper limit, Fig. 20). The lack of LERGs raises the question whether (some) MIR-weak HERGs were misclassified and actually belong to the LERG class. We checked the classification into low- and high-excitation emission line sources based on the ratio of  $[\text{O II}]/[\text{O III}] > 1$  (LERG) and  $[\text{O II}]/[\text{O III}] < 1$  (HERG), using the spectroscopic data from Jackson and Rawlings (1997) and Grimes *et al.* (2004). Due to the shift of the  $[\text{O III}]$  line from restframe wavelength of 5007 Å to infrared wavelengths only 7 sources of the medium-redshift sample (3C 207, 3C 220.1, 3C 254, 3C 263, 3C 265, 3C 280 and 3C 334) have measured  $[\text{O III}]$  fluxes. The other  $[\text{O III}]$  fluxes given by Grimes *et al.* (2004) have been extrapolated from Jackson and Rawlings (1997)  $[\text{O II}]$  fluxes using an average HERG line ratio. Therefore misclassification among the MIR-weak HERGs of the medium-redshift sample cannot be excluded.

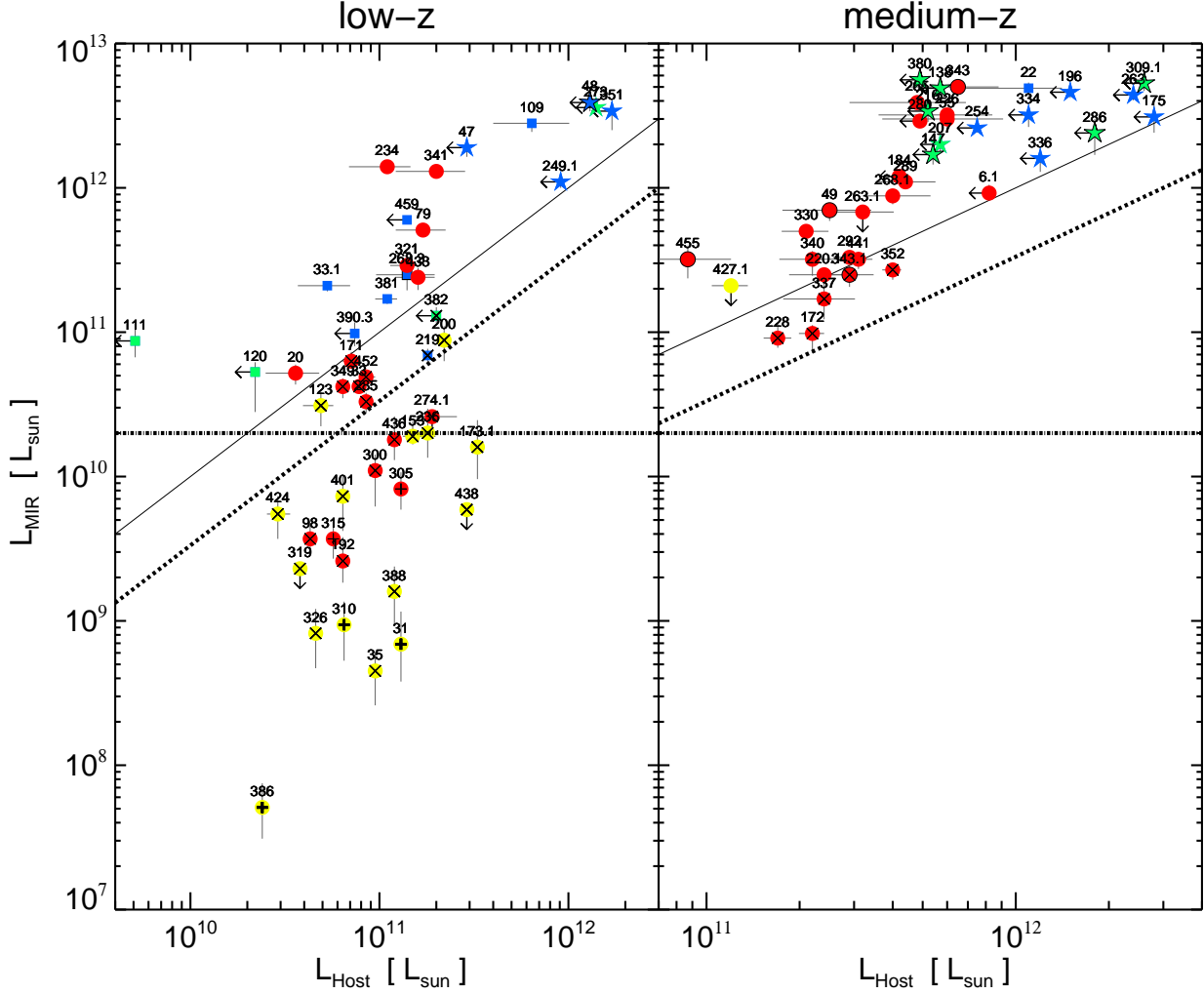


Fig. 20.— MIR vs host luminosities of the low (*left*) and medium (*right*) redshift samples. Circles indicate RGs (radio galaxies), stars indicate QSRs (quasars), squares BLRGs and arrows  $3\sigma$  upper limits. SSQ (Steep spectrum QSRs) are in blue, FSQ (Flat Steep-spectrum QSRs) in green, HERG (high excitation radio galaxies) in red, LERG (low excitation radio galaxies) in yellow, and CSS (compact steep spectrum sources) in black, crosses indicate MIR-weak, and plus FRI (Fanaroff-Riley class I) sources, respectively. The dividing ratio of  $L_{\text{MIR}}/L_{\text{Host}} = 1$  (solid line) separates the MIR-weak sources. A dividing ratio of  $L_{\text{MIR}}/L_{\text{Host}} = 1/3$  is denoted by the dotted line. The horizontal line at  $2 \times 10^{10} L_{\odot}$  corresponds to the absolute threshold defined by Ogle *et al.* (2006).

For the low-redshift sample the coverage of tabulated emission line data in [O II] and [O III] is better and consistent with the HERG classifications (except for the starburst galaxy 3C 459), but the classification could only be confirmed for one LERG (3C 236), the others have no emission line data available.

We find two MIR-weak BLRGs (3C 219 and 3C 382); they could be the broad-line counterparts of the otherwise type-2 dominated MIR-weak class. This finding is remarkable because type-1 AGN are typically brighter in the MIR than type-2 AGN, and the type-1 hosts are more difficult to measure. Nevertheless, the number ra-

tio of the type-1 / type-2 MIR-weak is small and a large dust covering angle would be required to reach consistency with orientation based unification schemes.

In the orientation-based AGN unification, MIR-weak sources either have less dust, a dust torus with a small covering angle or low accretion power. To distinguish between these scenarios is a particular challenge. MIR-weak sources are found among both HERGs and LERGs, indicating a potential smooth transition and arguing against sharply distinguished, fundamentally different mechanisms like "radiation dominated" vs. "advection dominated" accretion (Ogle *et al.* 2006).

## 5.2. Comparison of MIR to radio-lobe and [O III] luminosities

Three luminosities in MIR, radio-lobe and [O III] luminosities are expected to be tracers of the intrinsic AGN accretion power and therefore should be correlated. Fig. 21 (right) shows the ratio  $L_{\text{MIR}}/L_{\text{OIII}}$ , which appears similar over four orders of magnitude for all three classes QSRs, HERGs and LERGs. The relation was fitted for all classes (see Eq. 17) and for the LERGs separately (see Eq. 18). There is a trend that LERGs have about a factor 3 higher  $L_{\text{OIII}}$  compared to QSRs and HERGs of the same  $L_{\text{MIR}}$  (all LERGs except 3C 236 lie on the right side of the median relationship in Fig. 21,(right)). This trend can be explained by differences in the dust torus or intrinsic difference in the AGN-SED of high- and low-excitation sources. A smaller torus covering angle and less extinction of the inner NLR might be the cause. Also a central engine with a lower production rate of ionizing photons is thinkable. Best-fit relations are:

$$\log(L_{\text{MIR}}^{\text{All}}/L_{\odot}) = (2.4 \pm 0.8) + (1.0 \pm 0.1) \times \log(L_{\text{OIII}}/L_{\odot}) \quad (17)$$

$$\log(L_{\text{MIR}}^{\text{LERG}}/L_{\odot}) = (1.9 \pm 0.7) + (1.0 \pm 0.1) \times \log(L_{\text{OIII}}/L_{\odot}) \quad (18)$$

In Fig. 21 (left) the monochromatic radio-lobe luminosity is plotted versus the MIR luminosity. The distributions for the different classes of

QSRs, HERGs and LERGs show a clear overall trend. The correlations for QSRs, HERGs and LERGs are fitted separately (see Eq. 19 - 21). At  $\nu L_{\nu}^{178 \text{ MHz}} = 5 \cdot 10^9 L_{\odot}$  the low from the medium-redshift sample are separated; there are only three low- $z$  exceptions (3C 47, 3C 48 and 3C 123) exceeding that radio luminosity threshold.

$$\log(L_{\text{MIR}}^{\text{QSR}}/L_{\odot}) = (6.3 \pm 0.6) + (0.61 \pm 0.07) \times \log(L_{\nu}^{178 \text{ MHz}}/L_{\odot}) \quad (19)$$

$$\log(L_{\text{MIR}}^{\text{HERG}}/L_{\odot}) = (4.0 \pm 0.9) + (0.8 \pm 0.1) \times \log(L_{\nu}^{178 \text{ MHz}}/L_{\odot}) \quad (20)$$

$$\log(L_{\text{MIR}}^{\text{LERG}}/L_{\odot}) = (3.3 \pm 1.1) + (0.8 \pm 0.1) \times \log(L_{\nu}^{178 \text{ MHz}}/L_{\odot}) \quad (21)$$

The HERGs and LERGs show a remarkably similar  $L_{\text{MIR}}/L_{\nu}^{178 \text{ MHz}}$  slope, apart from the offset, while the quasars show a flatter  $L_{\text{MIR}}/L_{\nu}^{178 \text{ MHz}}$  slope. The torus models do not properly account for the hot ( $\sim 1000 \text{ K}$ ) dust emission in type-1 sources. This was already noted by Leipski *et al.* (2013) and Podigachoski *et al.* (2015a) for the high- $z$  quasars. Thus the integrated luminosity  $L_{\text{MIR}}$  from the fitted torus models is underestimating the MIR luminosities of the bright quasars. Independent of the slopes, the MIR/radio ratio of QSRs exceeds that of the HERGs by a factor of 5-10. This can be explained by orientation-dependent extinction even at MIR wavelengths (e.g. Haas *et al.* 2008; Leipski *et al.* 2010; Podigachoski *et al.* 2015b).

Likewise, both LERGs and MIR-weak HERGs show a 2-20 times weaker  $L_{\text{MIR}}/\nu L_{\nu}^{178 \text{ MHz}}$  ratio than the MIR-strong HERGs which is rather caused by decreased MIR than increased radio luminosity. Differences in the central engine can cause different AGN SEDs or low dust content may be the reason for MIR weakness; for example a binary black hole or differences in the black hole spin could lead to strong jet development on lower accretion rates.

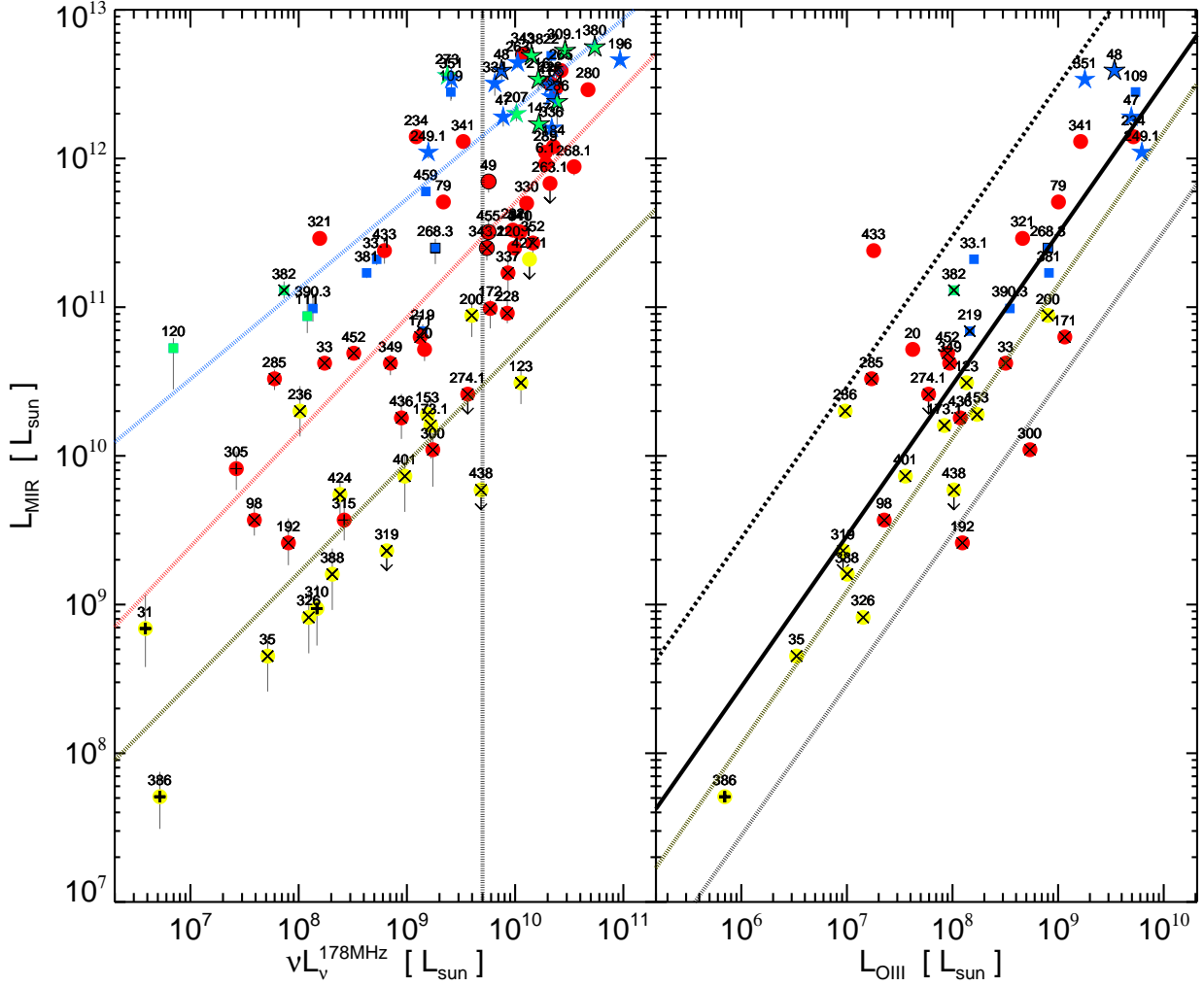


Fig. 21.— *left*: MIR luminosity versus radio luminosity. The vertical dashed line at  $5 \cdot 10^9 L_{\odot}$  radio power roughly separates the medium from the low-redshift sample (exceptions are the low- $z$  sources 3C 47, 3C 48 and 3C 123). The colored dotted lines denote fits to the SSQs (blue), HERGs (red) and LERGs (yellow). *right*: MIR luminosity versus [O III] luminosity. Only observed [O III] fluxes from (Grimes *et al.* 2004) are included. Black solid line denotes median relation of all plotted sources. Dashed and dotted black lines denote one dex range from median relation. Yellow dotted line denotes median relation for LERGs. Notation as in Fig. 20.

### 5.3. IR and radio luminosity ratios

#### 5.3.1. Beamed IR contribution in FSQs

At medium redshifts the SSQs 3C 334 and 3C 336 (and also some HERGs) have such low 1.2 mm fluxes observed (Haas *et al.* 2004) that there is no room for a beamed synchrotron component (with reasonable spectral slope  $\alpha$ ) to contribute to the MIR and FIR (Fig. 2). This is

comparable to radio-quiet quasars as seen by Chini *et al.* (1989). The other 6 SSQs do not have 1.2 mm measurements, but the same picture can be assumed for them.

In contrast the 7 FSQs have a rising GHz spectrum and beamed emission may contribute to the FIR and MIR (Fig. 1). A strong FIR contribution is immediately obvious for 3C 138, 3C 216 and 3C 286. In the MIR, however, a sharp bump at

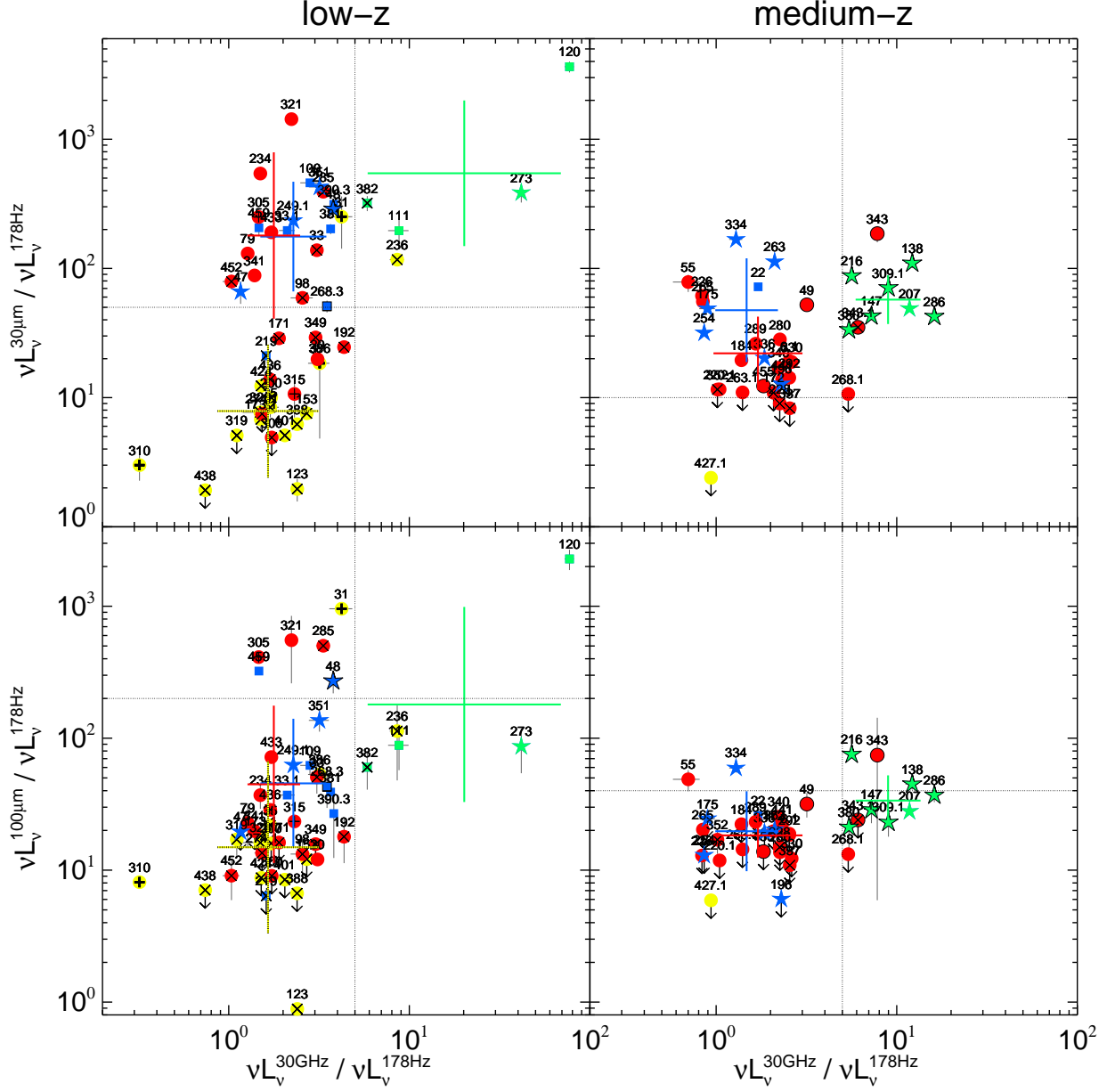


Fig. 22.— IR and radio luminosity ratios for low (*left*) and medium (*right*) redshift samples.  $R_{\text{DR}} = \nu F_{\nu}^{\text{IR}} / \nu F_{\nu}^{178 \text{ MHz}}$  at 30 and 100  $\mu\text{m}$  are shown in the top and bottom panels respectively. Large crosses give the logarithmic mean and the dex range of the HERGs (red), LERGs (yellow), SSQs (blue) and all FSQs (green), CSS are excluded. The vertical dotted line at  $R_{\text{GM}} = 5$  separates FSQs from the other AGN types. The horizontal dotted lines separate in the top panels (low- $z$ :  $R_{\text{DR}} = 50$ , medium- $z$ :  $R_{\text{DR}} = 10$ ) LERGs and MIR-weak sources, and in the bottom panels (low- $z$ :  $R_{\text{DR}} = 200$ , medium- $z$ :  $R_{\text{DR}} = 40$ ) FIR/radio excess sources. Notation as in Fig. 20.

$\sim 20 \mu\text{m}$  can be identified in most sources, except 3C 207 and 3C 216. Also the NIR 3–4  $\mu\text{m}$  bump is discernible (e.g., 3C 147). This suggests that the NIR–MIR SED is dominated by dust emission and that any beamed contribution to the MIR and NIR is weaker than in the FIR. The same picture can be seen at lower redshifts for the FSQs in Fig. 8, where the non-thermal contribution can be traced to the FIR for 3C 111, 3C 120, 3C 273 and 3C 382. The SSQs and BLRGs plots show (Fig. 9 and 10) that the FIR is dominated by dust emission.

Following the concept introduced by Meisenheimer et al. (2001), we determined the dust-to-radio ratio  $R_{\text{DR}} = \nu F_{\nu}^{\text{IR}} / \nu F_{\nu}^{178 \text{ MHz}}$  at 30 and 100  $\mu\text{m}$ . To quantify the dependence of  $L_{\text{IR}}$  at 30 and 100  $\mu\text{m}$  on the radio slope, we consider  $R_{\text{DR}}$  versus  $R_{\text{GM}} = \nu L_{\nu}^{30 \text{ GHz}} / \nu L_{\nu}^{178 \text{ MHz}}$  (Fig. 22).  $R_{\text{GM}}$  clearly separates FSQs from SSQs, with a dividing ratio  $R_{\text{GM}} = 5$ . Fig. 22 shows on the vertical axes the  $R_{\text{DR}}$  distributions at 30, and 100  $\mu\text{m}$  for the different AGN types. The large crosses mark the averages (in log space) and the dex range for the different AGN types:

- yellow/black: LERGs, excluding FRI and 3C 236 as outlier
- red: HERGs, excluding CSS, FRI and MIR-weak sources
- blue: SSQs, i.e. steep spectrum QSRs and BLRGs excluding CSS
- green: FSQs, i.e. flat spectrum QSRs and BLRGs

### 5.3.2. Cosmological evolution of radio activity

$R_{\text{DR}}^{30 \mu\text{m}} = 10$  for the medium-redshift sample and  $R_{\text{DR}}^{30 \mu\text{m}} = 50$  for the low-redshift sample can be used as a separator of MIR-weak and MIR-strong sources.  $R_{\text{DR}}^{100 \mu\text{m}} = 200$  for the low- and  $R_{\text{DR}}^{100 \mu\text{m}} = 40$  for the medium-redshift sample separate sources with an exceptional high FIR luminosity like 3C 321 or the CSS 3C 48; the curved radio spectrum of the CSS leads to an even lower 178 MHz flux. This check reveals that statistically  $L_{\text{FIR}}$  is higher by a factor of 2–3 in the FSQs. In contrast the MIR luminosity is similar (except 3C 120), which can be explained by a wavelength-independent constant contribution of non-thermal

radiation, which is more dominant in the sources with weaker (about 3 times) IR emission.

Fig. 22 shows a remarkable  $R_{\text{DR}}^{30 \mu\text{m}}$  and  $R_{\text{DR}}^{100 \mu\text{m}}$  difference between the low and medium redshift samples of SSQs and MIR-strong HERGs. For the medium- $z$  sample, on average,  $R_{\text{DR}}$  is about a factor 5–10 lower than for the low- $z$  sample. This indicates that at a given MIR AGN power the radio lobes are much fainter in the local universe compared to the earlier epoch. Thus, the lobe production via working surface of the jet with the ambient medium is less efficient. Notably,  $R_{\text{DR}}$  of the local MIR-weak HERGs matches that of the distant MIR-strong HERGs and the local LERGs have the lowest  $R_{\text{DR}}$ . This may indicate that their circumgalactic medium is denser, perhaps due to cluster environment (further discussed in Sect. 5.5).

### 5.3.3. SSQ / MIR-strong HERG unification

Both the radio-lobe luminosity  $\nu L_{\nu}^{178 \text{ MHz}}$  and the dust luminosity  $L_{\text{FIR}}$  are assumed to be isotropic. In the orientation-based unified scheme, their distributions should be indistinguishable for steep spectrum quasars (SSQs) and high-excitation radio galaxies (HERGs). The same should hold for *ratios* of isotropic observables. If the distributions differ, then either the observables are not isotropic or the sources have intrinsic differences. For the low-redshift sample the HERGs (with the MIR-weak ones excluded) and SSQs sub-samples show a nearly perfect match in logarithmic average and range (Fig. 22). FRI and CSS sources were excluded from the average for both classes.

For the medium-redshift sample the SSQs show a  $R_{\text{DR}}$  ratio at 30  $\mu\text{m}$  that is on average a factor of two higher than the HERGs, but the samples match in their average  $R_{\text{DR}}$  at 60  $\mu\text{m}$  and even better at 100  $\mu\text{m}$ . This can be interpreted by a dust torus that is optically thick at 30  $\mu\text{m}$  and emits isotropically at 100  $\mu\text{m}$ . Also the FSQs match with SSQs in the unification framework by synchrotron contribution from beamed jet emission in FIR and MIR. The match at 100  $\mu\text{m}$  may be favoured by the fact that the averages are dominated by the match of the upper limits. Again MIR-weak and CSS sources were excluded.

These results support the orientation-based



unified scheme for MIR-strong HERGs and SSQs. However, the relationship to LERGs and MIR-weak HERGs might not be explained simply by orientation effects, as discussed in Sect. 5.5.

#### 5.4. Star formation

To estimate the star forming luminosity  $L_{\text{FIR}}$  we assume that the FIR emission fitted by the  $\sim 30$  K modified blackbody is entirely powered by stars. However, the AGN may heat dust at lower temperatures than accounted for by the torus models of Hönig *et al.* (2010); in cases of different chemical dust composition and grain geometries the AGN create larger emission at longer wavelengths (Siebenmorgen *et al.* 2015). Therefore  $L_{\text{FIR}}$  and the SFR derived from our SED fits may be overestimated and the actual SFR may be smaller. Therefore we treat our estimates as maximum possible SFR. Other star formation indicators, e.g., via optical Balmer or [O II] lines, may suffer even more from AGN contamination than the FIR. In fact there is evidence (Hes *et al.* 1993) that isotropic [O II] emission from the narrow-line region is playing an important role in quasars and radio galaxies.

To provide a tentative cross check, we have converted both  $L_{\text{FIR}}$  and  $L_{\text{O II}}$  into star formation rates  $\text{SFR}_{\text{FIR}}$  and  $\text{SFR}_{\text{O II}}$  using the scaling relations (Eq. 7 and 22, Kennicutt 1998).

$$\text{SFR} \left[ \frac{M_{\odot}}{\text{yr}} \right] = (1.4 \pm 0.4) \times 10^{-41} L_{\text{O II}} \left[ \frac{\text{erg}}{\text{s}} \right] \quad (22)$$

The SFRs derived from both indicators match within an order of magnitude (Fig. 23). There is no correlation between  $\text{SFR}_{\text{O II}}$  and  $\text{SFR}_{\text{FIR}}$  in the medium-redshift sample, where a higher AGN-triggered [O II] emission has to be taken into account. For the low-redshift sample we find correlation but  $\text{SFR}_{\text{O II}}$  is larger than  $\text{SFR}_{\text{FIR}}$ . Because we have not subtracted AGN contributions from  $L_{\text{O II}}$  we suggest that  $\text{SFR}_{\text{O II}}$  is overestimated as well.

For most 3CR sources the ratio  $L_{\text{FIR}}/L_{\text{Host}} < 1$  is below that of the Milky Way. This suggests that the bulk of the sources contains a small amount of interstellar matter, which serves as a gas reservoir for star formation. To estimate the dust mass  $M_{\text{D}}$  from  $L_{\nu}^{100 \mu\text{m}}$  and the dust temperature  $T_{\text{D}}$ , we used

$$M_{\text{D}} = \frac{D_{\text{L}}^2 F_{\nu}}{\kappa_{\nu} B_{\nu}(T_{\text{D}})} \quad (23)$$

with dust opacity  $\kappa_{100 \mu\text{m}} = 27 \text{ cm}^2/\text{g}$  (Draine 2003; Siebenmorgen *et al.* 2014). The dust masses are listed in Tables 14 and 15. For all but a handful starbursting 3CRs (identified below), the dust-to-stellar mass ratio lies in the range  $10^{-3} - 10^{-5}$ . That is about a factor 1–100 lower than for the Milky Way, i.e. more reminiscent of dust-poor elliptical galaxies. Despite large uncertainties in the dust mass estimates ( $M_{\text{D}}$  is especially sensitive to  $T_{\text{D}}$ ), this strongly suggests that the bulk of the 3CRs contains only a relatively small dust mass (and gas mass as well). If the dust mass is widely distributed across the host galaxy, this results in a low dust column density, and one may expect only a modest amount of overall optical extinction. This may explain the rough agreement between  $\text{SFR}_{\text{O II}}$  and  $\text{SFR}_{\text{FIR}}$ .

In the following we use  $\text{SFR}_{\text{FIR}}$ . For comparison with other galaxy types and across cosmic time, the derived SFR has to be placed in the context of the already existing stellar mass  $M_{\text{Host}}$ , derived from the host luminosity via the intrinsic mass-to-light ratio of the synthetic stellar population fits of the SEDs (Table 10). For FSQs  $L_{\text{FIR}}$  might be overestimated due to synchrotron contamination and SFR upper limits are plotted. For type-2 AGN and steep-spectrum BLRGs,  $M_{\text{Host}}$  and SFR are not affected this way.

For QSRs (SSQs and FSQs) the host luminosity is likely overestimated, and we therefore plot upper limits for  $M_{\text{Host}}$  of these sources. We find some sources in the medium redshift sample, e.g. 3C 343 or 3C 6.1, with stellar masses up to  $\approx 10^{12} M_{\odot}$ , which are rare in the local universe ( $z < 0.3$ ), but also have been reported recently for quasar host galaxies at redshifts  $< 1$  (see Fig. 7 of Matsuoka *et al.* (2015)). For three sources (3C 6.1, 3C 184 and 3C 280) there is no optical data available. In these sources the host fit is based on the WISE measurements where confusion within the WISE beam can not be excluded. Thus the host luminosity and derived stellar masses are treated as upper limits.

For the low-redshift sample the stellar masses lie in the range of  $10^{10}$  up to  $10^{12} M_{\odot}$ , and the FIR luminosities are about  $10^{10} L_{\odot}$  (Tables 11 and 15). In Figure 24 (left) the results are plotted to-

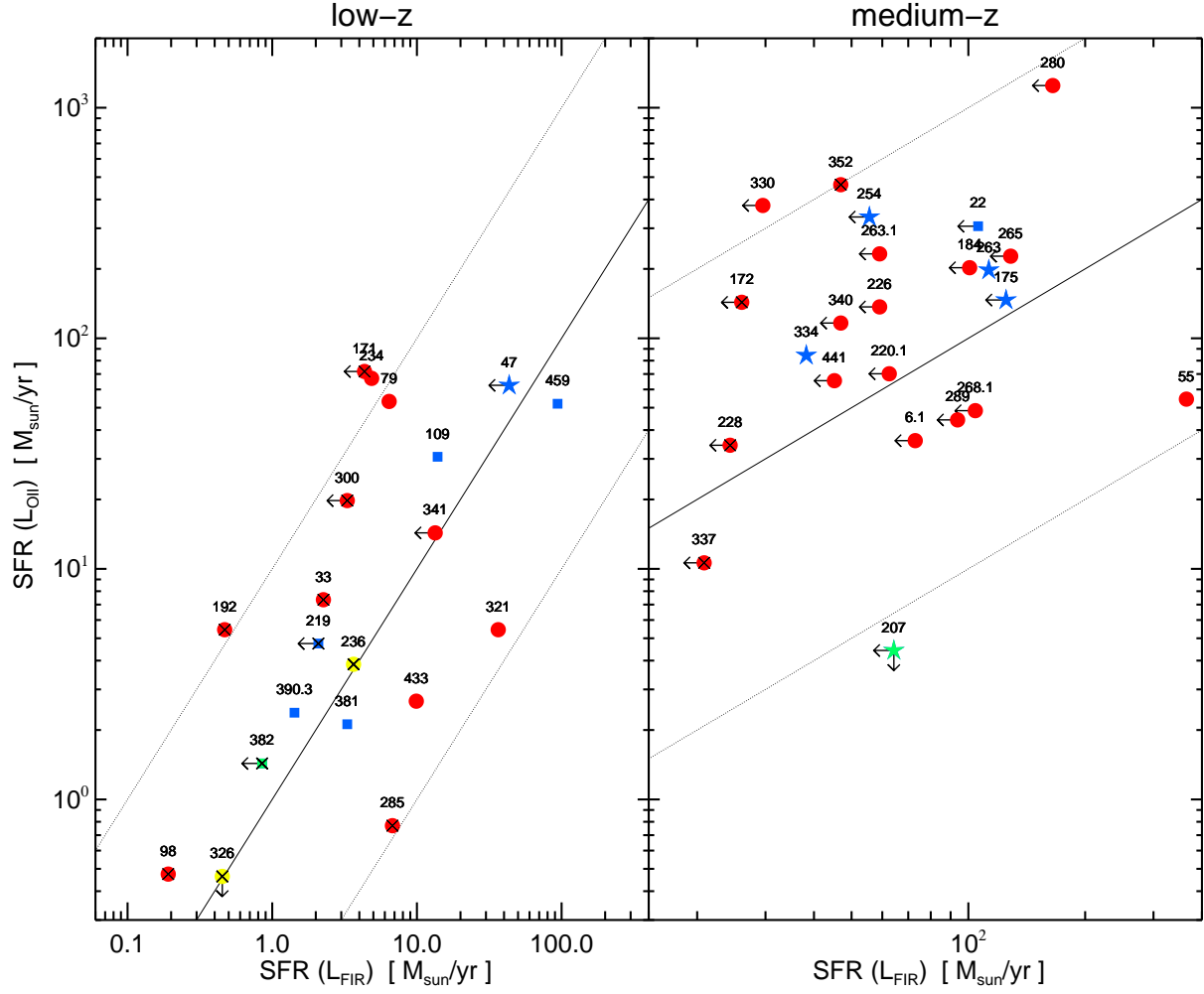


Fig. 23.— Star formation rate derived from [O II] versus that from FIR for the low and medium-redshift sample (left/right panel).  $L_{\text{O II}}$  is taken from Jackson and Rawlings (1997) and  $L_{\text{FIR}}$  from our modified blackbody fit. The lines are not a fit; they illustrate the overall agreement with slope unity (solid) and a factor 10 above/below unity (dotted). Notation as in Fig. 20.

gether with a comparison sample of SDSS galaxies in the redshift range  $0.015 < z < 0.1$  investigated by Brinchmann *et al.* (2004) and Kauffmann *et al.* (2003). The relation between SFR and mass for the SDSS galaxies is:

$$\text{SFR}_{\text{SDSS}} \left[ \frac{M_{\odot}}{\text{yr}} \right] = 8.7[-3.7, +7.4] \times \left[ \frac{M_{\star}}{10^{11} M_{\odot}} \right]^{0.77} \quad (24)$$

For the medium-redshift sample the range of

$L_{\text{FIR}}$  lies around  $10^{11} L_{\odot}$  (Fig. 24 right, Table 14), i.e., that of IR luminous SF galaxies (LIRGs) with a few sources above  $10^{12} L_{\odot}$  in the regime of ULIRGs. Derived host masses lie in the range of  $10^{11} - 10^{12} M_{\odot}$ , hence in the range of the most massive galaxies. For comparison a selection of star forming galaxies from the GOODS fields (Elbaz *et al.* 2007) with  $10^9 M_{\odot} < M_{\star} < 10^{12} M_{\odot}$ ,  $1 M_{\odot} \text{yr}^{-1} < \text{SFR} < 300 M_{\odot} \text{yr}^{-1}$ ,  $0.8 < z < 1.2$  has:

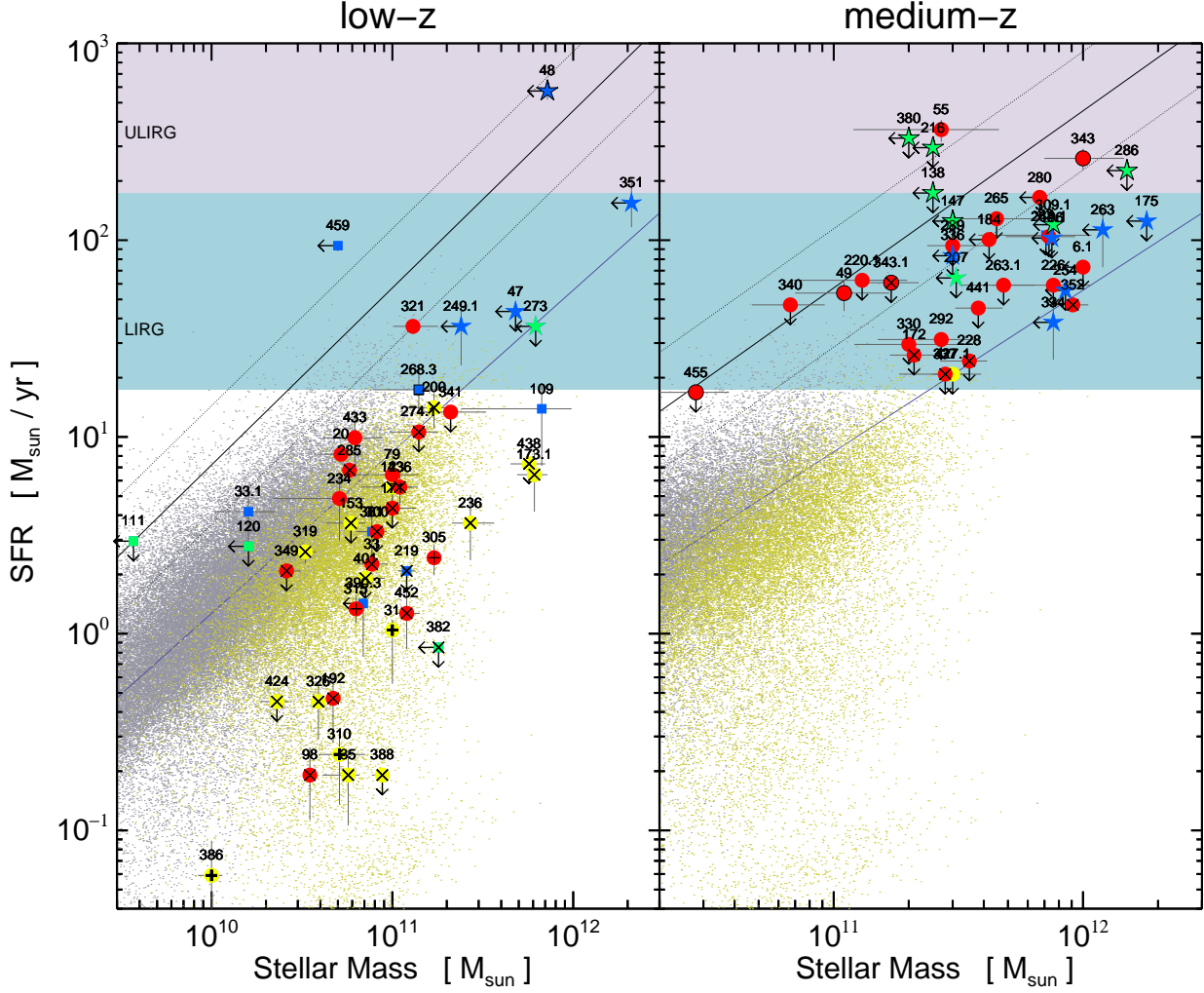


Fig. 24.— Star formation rates, SFR vs stellar mass of the host for the low (left) and medium-redshift (right) samples. The blue and violet shaded areas mark the range of LIRGs and ULIRGs. The clouds of small grey and yellow dots indicate the main sequence of star forming galaxies and AGN, respectively, at low-redshift ( $0.015 < z < 0.1$ ) from Brinchmann *et al.* (2004) and Kauffmann *et al.* (2003)) with the thin blue line representing the average relation of the star forming galaxies (Elbaz *et al.* 2007). The thick black line flanked by the black dotted lines shows the average relation and  $1\sigma$  of the  $0.8 < z < 1.2$  GOODS star forming galaxies from Elbaz *et al.* (2007). The location of the main sequence of star forming galaxies shifts up with increasing redshift Noeske *et al.* (2007). Notation as in Fig. 20.

$$\text{SFR}_{\text{GOODS}} \left[ \frac{M_{\odot}}{\text{yr}} \right] = 7.2[-3.6, +7.2] \times \left[ \frac{M_{\star}}{10^{10} M_{\odot}} \right]^{0.9} \quad (25)$$

To provide a panoptic view, in Figure 24 the whole investigated 3CR sample is shown together

with the appropriate comparison samples. The bulk of 3CR galaxies show only a small specific star formation rate for their epoch. The few exceptions are 3C 49, 3C 55 and 3C 343 for the medium-redshift sample and 3C 48, 3C 321 and 3C 459 for the low-redshift sample.

For the HERG, LERG and BLRG class, both

stellar masses and star formation rates establish that the 3Cs at  $z < 1$  belong to the most massive galaxies of their epoch, but most have low specific star forming activity. This is remarkably different from the results for 3CR sources at  $1 < z < 2$  (Podigachoski *et al.* 2015a), where  $\approx 40\%$  show ULIRG-like SFRs ( $200\text{--}2000 M_{\odot}/\text{yr}$ ) at similar host masses ( $10^{11}\text{--}10^{12} M_{\odot}$ ). This comparison suggests that many of the 3CRs at  $z < 1$  are in a late evolutionary state. Alternatively, if their nuclear activity is triggered by galaxy interactions/mergers, these could be dry mergers, i.e., the collision of two ISM-poor ellipticals. Strikingly, the MIR-weak sources and LERGs populate the lowest end of the specific SFR distributions.

### 5.5. Evolution from HERGs over MIR-weak to LERGs?

The possibility that MIR-weak sources and LERGs may be considered as classically accreting AGN in which the dust torus has a small covering angle, and where a low extinction enables bright [O II] emission, and where the environment favours a high radio lobe luminosity is raised in Sec. 5.1 and 5.2. MIR-weak sources and LERGs populate the low end of the FIR  $R_{\text{DR}}$  distributions (Fig. 22). The overall trends in Fig. 22 make an evolutionary HERG-to-LENG scenario attractive, in which MIR-strong HERGs evolve to MIR-weak HERGs and then further to LERGs. In this picture both the AGN accretion luminosity as traced by the dust torus and the SF luminosity (and the dust and gas mass) are high for young sources and decline with increasing age. However, there are several open issues with such a picture, as already discussed by Ogle *et al.* (2006), who suggested that the LERGs are jet-dominated sources with low, if any, accretion power. Here we can add more pieces to the puzzle:

a) In the low- $z$  sample the LERGs and MIR-weak HERGs populate the same host and radio lobe luminosity ranges as the MIR strong HERGs and QSRs (Figs. 20 and 21). The same holds for the lobe extent. If accretion plays a substantial role in creating the radio power, one would have to postulate that with declining accretion during the HERG-to-LENG transition another power source grows, in order to keep the lobe power similar for LERGs and HERGs. If accretion plays a subordinate role, then the jet power may be provided

by other processes such as a spinning or a binary black hole in the nucleus.

b) If the evolutionary HERG–LENG scenario is valid, one may expect that it holds also at higher luminosities/redshifts. In the medium- $z$  sample, however, MIR-weak sources (and LERGs) are rare, even with our new definition of MIR-weakness, and despite the denser circumgalactic medium compared to the local universe. The five MIR-weak sources have the lowest lobe power among the medium- $z$  sample (Fig. 21). This suggests that the MIR-weak successors of MIR-strong HERGs at  $0.5 < z < 1$  decline in lobe luminosity, so that they fall below the 178 MHz flux limit of the 3CR sample. The time scales of radio loudness are in the order of several  $10^7$  years, much shorter than the age range of the sample. Thus, any LENG-successors of MIR-strong HERGs of the  $0.5 < z < 1$  3CR sample cannot have moved out of that redshift range. For example  $t(z = 0.55) - t(z = 0.53) \approx 1.5 \cdot 10^8 \text{ yr}$  (Wright 2006).

c) Another possibility is that MIR-weak sources and LERGs do not exist in the early, say  $z > 0.75$  universe and have recently evolved. This may be related to the findings based on the Molonglo 2 Jy radio galaxies that LERGs are more frequently found in clusters than QSRs/BLRGs or HERGs (Ramos Almeida *et al.* 2013). Then the intra-cluster gas may enhance the radio lobes, as found for Cygnus A by Barthel & Arnaud (1996). Because the time scale for cluster formation is much higher than the radio-loud phase, a MIR-strong HERG in the field cannot evolve in several  $10^7$  years into a LENG surrounded by a cluster.

To summarize, there are several arguments against a simple evolutionary HERG-to-LENG scenario, and much future work is required to solve the puzzle on the relation between the MIR-weak and MIR-strong sources.

## 6. Summary and conclusions

a) The  $z < 0.5$  sample contains many LERGs, the medium-redshift sample many FSQs and in general more powerful RGs/QSRs. Complete photometry from diverse catalogues was collected for all sources to cover the SEDs continuously from optical to radio wavelengths.

b) The new SEDs were used to measure host,

AGN and star forming luminosities by fitting appropriate templates with a Metropolis-Hastings algorithm, based on maximizing the Bayesian posterior probability. Also model-independent luminosities were derived at selected wavelength, to quantify opacity effects and non-thermal contributions from synchrotron emission.

c) The class of MIR-weak sources was investigated. A new flux-ratio-dependent definition of MIR-weakness is given, which avoids an absolute threshold. Compared to the previous definition, now MIR-weak sources can clearly be separated also at higher luminosities. Possible explanations of the MIR weakness are either an extreme cool and thin dust torus or a lane seen directly from the edge. The MIR-weak sources can also represent an intrinsically different class of gas- and dust-poor AGN. Such a class may have suffered from evolutionary depletion by an early strong merger history in a more clustered environment.

d) The dust-to-radio-lobe luminosity ratios were calculated in the range of  $30 - 100 \mu\text{m}$ . This results in confirmation of the unification hypothesis of HERGs and QSRs.

e) The sample reveals a decline of the radio-lobe-to-dust luminosity ratio with increasing redshift. This indicates a decline of the efficiency to create radio lobes from early epochs up to today. We suggest that this is caused by the dilution of the circumgalactic medium during cosmic evolution.

f) For the whole sample, stellar masses and star formation rates were presented. This allows us to put the host galaxies of radio-loud AGN into context with non-AGN and radio-quiet AGN at the same epoch. The analysis shows that radio-loud AGN are associated with the most-massive galaxies ( $10^{10} \lesssim M_{\star} \lesssim 10^{12}$ ). In the majority of these galaxies new stars are formed only at a low level. The SFR may even be smaller if the AGN-heated dust torus contributes more at longer wavelength than indicated by currently available models.

Altogether, the present Herschel observations of the 3CRs at  $z < 1$  do not support the hypothesis that every radio-loud quasar is accompanied by a high specific star forming activity. Our analysis suggests that, if radio-loud AGN are triggered by galaxy interactions (Heckmann et al. 1986, Stock-

ton et al. 1986), in most cases these are probably dry mergers with little dust and gas mass.

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## REFERENCES

- Agudo, I., Thum, C., *et al.* (2010). *ApJS*, **189**, 1–14.
- Algaba, J. C., Gabuzda, D. C., *et al.* (2011). *MNRAS*, **411**, 85–101.
- Andreani, P., Fosbury, R. A. E., *et al.* (2002). *A&A*, **381**, 389–400.
- Antonucci, R. (1993). *ARA&A*, **31**, 473–521.
- Aslanian, A. M., Dagkesamanskii, R. D., *et al.* (1968). *Astrofizika*, **4**, 129–134.
- Baldwin, J. E., Boysen, R. C., *et al.* (1985). *MNRAS*, **217**, 717–730.
- Barthel, P., Haas, M., *et al.* (2012). *ApJ*, **757**, L26.
- Barthel, P. D. (1989). *ApJ*, **336**, 606–611.
- Barthel, P. D. (1994). volume 54 of *Astronomical Society of the Pacific Conference Series*, page 175.
- Barthel, P. D. and Arnaud, K. A. (1996). *MNRAS*, **283**, L45–L49.
- Becker, R. H., White, R. L., *et al.* (1991). *ApJS*, **75**, 1–229.
- Becker, R. H., White, R. L., *et al.* (1995). *ApJ*, **450**, 559.
- Bell, E. F., McIntosh, D. H., *et al.* (2003). *ApJS*, **149**, 289–312.
- Bennett, A. S. (1962). *MNRAS*, **125**, 75.
- Bennett, C. L., Hill, R. S., *et al.* (2003). *ApJS*, **148**, 97–117.
- Bertin, E. and Arnouts, S. (1996). *A&AS*, **117**, 393–404.
- Borch, A., Meisenheimer, K., *et al.* (2006). *A&A*, **453**, 869–881.
- Brinchmann, J., Charlot, S., *et al.* (2004). *MNRAS*, **351**, 1151–1179.
- Bruzual, G. and Charlot, S. (2003). *MNRAS*, **344**, 1000–1028.
- Calzetti, D., Armus, L., *et al.* (2000). *ApJ*, **533**, 682–695.
- Cesarsky, C. J., Abergel, A., *et al.* (1996). *A&A*, **315**, L32–L37.
- Chen, X. and Wright, E. L. (2009). *ApJ*, **694**, 222–234.
- Chini, R., Kreysa, E., *et al.* (1989). *A&A*, **219**, 87–97.
- Chynoweth, K. M., Langston, G. I., *et al.* (2009). *AJ*, **138**, 287–294.
- Cleary, K., Lawrence, C. R., *et al.* (2007). *ApJ*, **660**, 117–145.
- Cohen, A. S., Lane, W. M., *et al.* (2007). *AJ*, **134**, 1245–1262.
- Colla, G., Fanti, C., *et al.* (1970). *A&AS*, **1**, 281.
- Colla, G., Fanti, C., *et al.* (1972). *A&AS*, **7**, 1.
- Condon, J. J., Cotton, W. D., *et al.* (1998). *AJ*, **115**, 1693–1716.
- De Breuck, C., Seymour, N., *et al.* (2010). *ApJ*, **725**, 36–62.
- Dicken, D., Tadhunter, C., *et al.* (2010). *ApJ*, **722**, 1333–1341.
- Draine, B. T. (2003). *ARA&A*, **41**, 241–289.
- Edge, D. O., Shakeshaft, J. R., *et al.* (1959). *MmRAS*, **68**, 37–60.
- Elbaz, D., Daddi, E., *et al.* (2007). *A&A*, **468**, 33–48.
- Fanaroff, B. L. and Riley, J. M. (1974). *MNRAS*, **167**, 31P–36P.
- Fanti, C., Fanti, R., *et al.* (1974). *A&AS*, **18**, 147–156.
- Fanti, C., Pozzi, F., *et al.* (2000). *A&A*, **358**, 499–513.
- Ficarra, A., Grueff, G., *et al.* (1985). *A&AS*, **59**, 255–347.
- Fioc, M. and Rocca-Volmerange, B. (1997). *A&A*, **326**, 950–962.
- Fu, H. and Stockton, A. (2009). *ApJ*, **696**, 1693–1699.
- Gear, W. K., Stevens, J. A., *et al.* (1994). *MNRAS*, **267**, 167.
- Geldzahler, B. J. and Kuhr, H. (1983). *AJ*, **88**, 1126–1132.
- Gilbert, G. M., Riley, J. M., *et al.* (2004). *MNRAS*, **351**, 845–890.
- Gold, B., Odegard, N., *et al.* (2011). *ApJS*, **192**, 15.
- Gower, J. F. R., Scott, P. F., *et al.* (1967). *MmRAS*, **71**, 49.
- Gregory, P. C. and Condon, J. J. (1991). *ApJS*, **75**, 1011–1291.
- Griffin, M. J., Abergel, A., *et al.* (2010). *A&A*, **518**, L3.
- Griffith, M. R., Wright, A. E., *et al.* (1995). *ApJS*, **97**, 347–453.
- Grimes, J. A., Rawlings, S., *et al.* (2004). *MNRAS*, **349**, 503–517.
- Haas, M., Klaas, U., *et al.* (2003). *A&A*, **402**, 87–111.
- Haas, M., Müller, S. A. H., *et al.* (2004). *A&A*, **424**, 531–543.
- Haas, M., Siebenmorgen, R., *et al.* (2005). *A&A*, **442**, L39–L43.
- Haas, M., Willner, S. P., *et al.* (2008). *ApJ*, **688**, 122–127.
- Haas, M., Leipski, C., *et al.* (2014). *ApJ*, **790**, 46.
- Hales, S. E. G., Baldwin, J. E., *et al.* (1988). *MNRAS*, **234**, 919–936.
- Hales, S. E. G., Masson, C. R., *et al.* (1990). *MNRAS*, **246**, 256.
- Hales, S. E. G., Mayer, C. J., *et al.* (1991). *MNRAS*, **251**, 46–53.
- Hales, S. E. G., Masson, C. R., *et al.* (1993). *MNRAS*, **262**, 1057–1061.
- Hales, S. E. G., Waldram, E. M., *et al.* (1995). *MNRAS*, **274**, 447–451.
- Hardcastle, M. J., Evans, D. A., *et al.* (2009). *MNRAS*, **396**, 1929–1952.
- Häring, N. and Rix, H.-W. (2004). *ApJ*, **604**, L89–L92.

- Heckman, T. M., Smith, E. P., *et al.* (1986). *ApJ*, **311**, 526–547.
- Heckman, T. M., Chambers, K. C., *et al.* (1992). *ApJ*, **391**, 39–47.
- Heckman, T. M., O’Dea, C. P., *et al.* (1994). *ApJ*, **428**, 65–81.
- Hes, R., Barthel, P. D., *et al.* (1993). *Nature*, **362**, 326–328.
- Hes, R., Barthel, P. D., *et al.* (1995). *A&A*, **303**, 8.
- Hoekstra, H., Barthel, P. D., *et al.* (1997). *A&A*, **319**, 757–763.
- Hönig, S. F. and Kishimoto, M. (2010). *A&A*, **523**, A27.
- Hönig, S. F., Beckert, T., *et al.* (2006). *A&A*, **452**, 459–471.
- Houck, J. R., Roellig, T. L., *et al.* (2004). *ApJS*, **154**, 18–24.
- Jackson, N. and Rawlings, S. (1997). *MNRAS*, **286**, 241–256.
- Jenness, T., Robson, E. I., *et al.* (2010). *MNRAS*, **401**, 1240–1254.
- Kassim, N. E., Lazio, T. J. W., *et al.* (2007). *ApJS*, **172**, 686–719.
- Kauffmann, G., Heckman, T. M., *et al.* (2003). *MNRAS*, **341**, 33–53.
- Kellermann, K. I. and Pauliny-Toth, I. I. K. (1973). *AJ*, **78**, 828–847.
- Kellermann, K. I., Pauliny-Toth, I. I. K., *et al.* (1969). *ApJ*, **157**, 1.
- Kennicutt, Jr., R. C. (1998). *ApJ*, **498**, 541–552.
- Kessler, M. F., Stein, J. A., *et al.* (1996). *A&A*, **315**, L27–L31.
- Klein, U., Vigotti, M., *et al.* (1996). *A&A*, **313**, 417–422.
- Kuehr, H., Witzel, A., *et al.* (1981). *A&AS*, **45**, 367–430.
- Laing, R. A. and Peacock, J. A. (1980). *MNRAS*, **190**, 903–924.
- Laing, R. A., Riley, J. M., *et al.* (1983). *MNRAS*, **204**, 151–187.
- Landsman, W. B. (1993). volume 52 of *Astronomical Society of the Pacific Conference Series*, page 246.
- Large, M. I., Mills, B. Y., *et al.* (1981). *MNRAS*, **194**, 693.
- Lebouteiller, V., Barry, D. J., *et al.* (2011). *ApJS*, **196**, 8.
- Lehnert, M. D., Miley, G. K., *et al.* (1999). *ApJS*, **123**, 351–376.
- Leipski, C., Haas, M., *et al.* (2010). *ApJ*, **717**, 766–775.
- Leipski, C., Meisenheimer, K., *et al.* (2013). *ApJ*, **772**, 103.
- Lister, M. L., Aller, M., *et al.* (2011). *ApJ*, **742**, 27.
- Mack, K.-H., Vigotti, M., *et al.* (2005). *A&A*, **435**, 863–870.
- Mantovani, F., Mack, K.-H., *et al.* (2009). *A&A*, **502**, 61–65.
- Matsuoka, Y., Strauss, M. A., *et al.* (2015). *ApJ*, **811**, 91.
- Meisenheimer, K., Haas, M., *et al.* (2001). *A&A*, **372**, 719–729.
- Mullin, L. M., Hardcastle, M. J., *et al.* (2006). *MNRAS*, **372**, 113–135.
- Nenkova, M., Ivezić, Ž., *et al.* (2002). *ApJ*, **570**, L9–L12.
- Netzer, H., Lutz, D., *et al.* (2007). *ApJ*, **666**, 806–816.
- Noeske, K. G., Weiner, B. J., *et al.* (2007). *ApJ*, **660**, L43–L46.
- Ochsenbein, F., Bauer, P., *et al.* (2000). *A&AS*, **143**, 23–32.
- Ogle, P., Whysong, D., *et al.* (2006). *ApJ*, **647**, 161–171.
- Ott, S. (2010). volume 434 of *Astronomical Society of the Pacific Conference Series*, page 139.
- Panther, B., Heavens, A. F., *et al.* (2004). *MNRAS*, **355**, 764–768.
- Pauliny-Toth, I. I. K., Wade, C. M., *et al.* (1966). *ApJS*, **13**, 65.
- Pilbratt, G. L., Riedinger, J. R., *et al.* (2010). *A&A*, **518**, L1.
- Pilkington, J. D. H. and Scott, J. F. (1965). *MmRAS*, **69**, 183.
- Podigachoski, P., Barthel, P. D., *et al.* (2015a). *A&A*, **575**, A80.
- Podigachoski, P., Barthel, P., *et al.* (2015b). *ApJ*, **806**, L11.
- Poglitsch, A., Waelkens, C., *et al.* (2010). *A&A*, **518**, L2.
- Polletta, M., Courvoisier, T. J.-L., *et al.* (2000). *A&A*, **362**, 75–96.
- Popesso, P., Magnelli, B., *et al.* (2012). *ArXiv e-prints*.
- Ramos Almeida, C., Bessiere, P. S., *et al.* (2013). *MNRAS*, **436**, 997–1016.
- Rengelink, R. B., Tang, Y., *et al.* (1997). *A&AS*, **124**, 259–280.
- Richards, J. L., Max-Moerbeck, W., *et al.* (2011). *ApJS*, **194**, 29.
- Rieke, G. H., Young, E. T., *et al.* (2004). *ApJS*, **154**, 25–29.
- Rowan-Robinson, M. (1995). *MNRAS*, **272**, 737–748.
- Sanders, D. B., Soifer, B. T., *et al.* (1988). *ApJ*, **328**, L35–L39.
- Sanders, D. B., Phinney, E. S., *et al.* (1989). *ApJ*, **347**, 29–51.
- Schweitzer, M., Lutz, D., *et al.* (2006). *ApJ*, **649**, 79–90.
- Shang, Z., Brotherton, M. S., *et al.* (2011). *ApJS*, **196**, 2.
- Shi, Y., Rieke, G. H., *et al.* (2005). *ApJ*, **629**, 88–99.
- Siebenmorgen, R., Freudling, W., *et al.* (2004). *A&A*, **421**, 129–145.
- Siebenmorgen, R., Voshchinnikov, N. V., *et al.* (2014). *A&A*, **561**, A82.
- Siebenmorgen, R., Heymann, F., *et al.* (2015). *A&A*, **583**, 1–18.
- Singal, A. K. (1993). *MNRAS*, **262**, L27–L30.

- Spergel, D. N., Bean, R., *et al.* (2007). *ApJS*, **170**, 377–408.
- Spinrad, H., Marr, J., *et al.* (1985). *PASP*, **97**, 932–961.
- Spoon, H. (2012). The Infrared Database of Extragalactic Observables from Spitzer (IDEOS). NASA Proposal #12-ADAP12-21.
- Steppe, H., Jeyakumar, S., *et al.* (1995). *A&AS*, **113**, 409.
- Stull, M. A. (1971). *AJ*, **76**, 1–4.
- Swindle, R., Gal, R. R., *et al.* (2011). *AJ*, **142**, 118.
- Tremaine, S., Gebhardt, K., *et al.* (2002). *ApJ*, **574**, 740–753.
- van Bemmell, I. M., Barthel, P. D., *et al.* (2000). *A&A*, **359**, 523–530.
- van der Wolk, G., Barthel, P. D., *et al.* (2010). *A&A*, **511**, A64.
- Veilleux, S., Rupke, D. S. N., *et al.* (2009). *ApJS*, **182**, 628–666.
- Véron-Cetty, M.-P. and Véron, P. (2010). *A&A*, **518**, A10.
- Waldram, E. M., Yates, J. A., *et al.* (1996). *MNRAS*, **282**, 779–787.
- Werner, M. W., Roellig, T. L., *et al.* (2004). *ApJS*, **154**, 1–9.
- Wiren, S., Valtaoja, E., *et al.* (1992). *AJ*, **104**, 1009–1017.
- Wright, E. L. (2006). *PASP*, **118**, 1711–1715.
- Wright, E. L., Chen, X., *et al.* (2009). *ApJS*, **180**, 283–295.
- Wright, E. L., Eisenhardt, P. R. M., *et al.* (2010). *AJ*, **140**, 1868–1881.



## A. Appendix material

### A.1. Tables

Table 7: Median SED composition at medium-redshift  $0.5 < z < 1.0$

FSQs	SSQs	HERGs		
3C138.0	3C022.0	3C049.0	3C263.1	3C172.0
3C147.0	3C175.0	3C055.0	3C289.0	3C220.1
3C207.0	3C196.0	3C184.0	3C330.0	3C228.0
3C216.0	3C254.0	3C226.0	3C455.0	3C268.1
3C286.0	3C263.0	3C265.0	3C340.0	3C292.0
3C309.1	3C334.0	3C280.0	3C343.1	3C337.0
3C380.0	3C336.0	3C343.0	3C441.0	3C352.0
		3C006.1		

Table 8: Median SED composition at low-redshift  $z < 0.5$  (3C 427.1 taken from medium-redshift sample)

FSQs	SSQs	BLRGs	HERGs		LERGs	
3C111.0	3C047.0	3C033.1	3C020.0	3C305.0	3C123.0	3C031.0
3C120.0	3C048.0	3C109.0	3C033.0	3C349.0	3C153.0	3C386.0
3C273.0	3C249.1	3C219.0	3C079.0	3C452.0	3C173.1	3C236.0
3C382.0	3C351.0	3C268.3	3C171.0	3C035.0	3C200.0	3C310.0
		3C381.0	3C234.0	3C192.0	3C319.0	3C388.0
		3C390.3	3C321.0	3C274.1	3C401.0	3C326.0
		3C459.0	3C341.0	3C300.0	3C424.0	3C427.1
			3C433.0	3C315.0	3C438.0	
			3C098.0	3C436.0		
			3C285.0			

Table 9: Model parameters

Host		Torus							FIR		
$A_{\text{Host}}$	Metal.	$v$	Age	$A_{\text{AGN}}$	i	N	a	$\theta$	$\tau$	$A_{\text{FIR}}$	$T_{\text{FIR}}$
(W/m <sup>2</sup> )		(logyr)	(logyr)	(W/m <sup>2</sup> )	(deg)			(deg)		(W/m <sup>2</sup> )	(K)
var. <sup>a</sup>	0-1 <sup>b</sup>	6.5-11	9-10.2	var. <sup>a</sup>	0-90 <sup>c</sup>	2.5-10 <sup>d</sup>	-2-0 <sup>e</sup>	5-60 <sup>f</sup>	30-80 <sup>g</sup>	var. <sup>a</sup>	var. <sup>a</sup>

<sup>a</sup>varies in the range of 200% to one 50% of individual start value

<sup>b</sup>the interval of [0, 1] corresponds to metallicities of Z=[0.004, 0.008, 0.02, 0.05]

<sup>c</sup>steps of 15 degree

<sup>d</sup>steps of 2.5

<sup>e</sup>steps of 0.5

<sup>f</sup>steps of [5,30,45,60]

<sup>g</sup>steps [30,50,80]

Table 10: Host fit parameters for the 3Cs at  $0.5 < z < 1.0$ 

Name	$A_{\text{Host}}[\log(\frac{W}{m\text{\AA}})]$	Z	$v$ [log(yr)]	Age [log(yr)]	$M_{\star}[10^{11}M_{\odot}]$	$L_{\text{Host}}[10^{11}L_{\odot}]$	$M_{\text{BH}}[10^7M_{\odot}]$
3C006.1	$-15.18^{+0.10}_{-0.11}$	0.008	$9.0^{+0.9}_{-0.9}$	$9.90^{+0.13}_{-0.16}$	$10.0^{+3.8}_{-3.9}$	$8.2^{+3.1}_{-2.1}$	$208.9^{+232.7}_{-123.3}$
3C022.0	$-15.18^{+0.10}_{-0.19}$	0.02	$10.0^{+0.3}_{-0.6}$	$9.50^{+0.09}_{-0.12}$	$7.1^{+3.7}_{-3.3}$	$11.0^{+3.1}_{-4.1}$	$142.4^{+188.3}_{-90.5}$
3C049.0	$-15.40^{+0.14}_{-0.14}$	0.008	$7.6^{+0.8}_{-0.7}$	$9.30^{+0.12}_{-0.06}$	$1.1^{+0.6}_{-0.4}$	$2.5^{+0.9}_{-0.7}$	$17.6^{+18.9}_{-9.0}$
3C055.0	$-15.21^{+0.18}_{-0.19}$	0.004	$8.1^{+1.6}_{-1.2}$	$9.50^{+0.07}_{-0.07}$	$2.7^{+1.9}_{-1.5}$	$6.0^{+3.1}_{-2.3}$	$48.2^{+72.6}_{-32.9}$
3C138.0	$-15.24^{+0.10}_{-0.22}$	0.02	$7.3^{+0.8}_{-0.4}$	$9.20^{+0.07}_{-0.16}$	$2.5^{+1.0}_{-1.0}$	$5.7^{+1.4}_{-2.3}$	$44.2^{+42.1}_{-24.6}$
3C147.0	$-14.92^{+0.04}_{-0.09}$	0.02	$6.9^{+0.6}_{-0.3}$	$9.30^{+0.16}_{-0.05}$	$3.0^{+1.0}_{-0.8}$	$5.4^{+0.5}_{-1.0}$	$54.2^{+48.2}_{-24.6}$
3C172.0	$-15.21^{+0.04}_{-0.05}$	0.05	$8.3^{+0.6}_{-1.1}$	$9.60^{+0.18}_{-0.09}$	$2.1^{+0.6}_{-0.4}$	$2.2^{+0.2}_{-0.2}$	$36.4^{+29.2}_{-14.6}$
3C175.0	$-14.54^{+0.09}_{-0.15}$	0.05	$8.1^{+0.6}_{-0.5}$	$9.30^{+0.25}_{-0.07}$	$18.0^{+3.7}_{-5.3}$	$28.0^{+7.8}_{-8.5}$	$403.6^{+349.8}_{-217.3}$
3C175.1	$-15.13^{+0.27}_{-0.14}$	0.05	$8.7^{+1.8}_{-1.4}$	$10.00^{+0.08}_{-0.13}$	$19.0^{+19.0}_{-7.2}$	$9.8^{+8.4}_{-2.7}$	$428.7^{+1030.6}_{-256.5}$
3C184.0	$-15.64^{+0.11}_{-0.12}$	0.02	$8.9^{+1.7}_{-0.8}$	$9.90^{+0.30}_{-0.17}$	$4.2^{+1.8}_{-1.3}$	$4.2^{+2.3}_{-1.2}$	$79.1^{+86.2}_{-40.2}$
3C196.0	$-14.96^{+0.07}_{-0.09}$	0.004	$7.5^{+0.8}_{-0.6}$	$9.40^{+0.07}_{-0.26}$	$7.5^{+2.3}_{-3.3}$	$15.0^{+2.8}_{-3.3}$	$151.4^{+143.5}_{-93.8}$
3C207.0	$-15.10^{+0.06}_{-0.12}$	0.05	$7.5^{+0.7}_{-0.7}$	$9.30^{+0.13}_{-0.20}$	$3.1^{+1.0}_{-1.0}$	$5.7^{+0.9}_{-1.3}$	$56.3^{+48.3}_{-28.6}$
3C216.0	$-15.15^{+0.16}_{-0.22}$	0.05	$7.5^{+1.1}_{-0.9}$	$9.30^{+0.18}_{-0.08}$	$2.5^{+1.6}_{-1.2}$	$5.2^{+2.2}_{-2.3}$	$44.2^{+61.2}_{-27.6}$
3C220.1	$-15.36^{+0.10}_{-0.10}$	0.05	$7.5^{+1.0}_{-0.7}$	$9.40^{+0.28}_{-0.27}$	$1.3^{+0.7}_{-0.6}$	$2.4^{+0.7}_{-0.5}$	$21.3^{+23.1}_{-12.8}$
3C220.3	$-15.17^{+0.18}_{-0.20}$	0.008	$7.9^{+0.9}_{-1.1}$	$9.60^{+0.13}_{-0.14}$	$3.7^{+2.5}_{-1.8}$	$5.2^{+2.5}_{-2.0}$	$68.6^{+103.2}_{-43.8}$
3C226.0	$-15.23^{+0.15}_{-0.23}$	0.05	$7.6^{+1.0}_{-0.7}$	$9.70^{+0.17}_{-0.10}$	$7.6^{+3.1}_{-2.4}$	$6.0^{+2.4}_{-2.4}$	$153.6^{+173.5}_{-94.6}$
3C228.0	$-15.39^{+0.04}_{-0.05}$	0.02	$9.2^{+1.4}_{-2.0}$	$10.00^{+0.07}_{-0.11}$	$3.5^{+0.6}_{-0.8}$	$1.7^{+0.2}_{-0.2}$	$64.5^{+41.6}_{-28.8}$
3C254.0	$-15.06^{+0.03}_{-0.06}$	0.008	$8.2^{+0.9}_{-0.6}$	$9.80^{+0.10}_{-0.16}$	$8.5^{+2.4}_{-2.2}$	$7.5^{+0.8}_{-1.1}$	$174.2^{+160.2}_{-85.6}$
3C263.0	$-14.42^{+0.07}_{-0.09}$	0.05	$7.0^{+0.6}_{-0.4}$	$9.20^{+0.06}_{-0.10}$	$12.0^{+2.7}_{-2.4}$	$24.0^{+4.2}_{-4.8}$	$256.3^{+219.5}_{-117.8}$
3C263.1	$-15.57^{+0.10}_{-0.12}$	0.004	$8.9^{+1.5}_{-1.9}$	$10.00^{+0.08}_{-0.14}$	$4.8^{+1.6}_{-1.6}$	$3.2^{+0.8}_{-0.8}$	$91.8^{+86.5}_{-48.6}$
3C265.0	$-15.32^{+0.15}_{-0.15}$	0.05	$7.7^{+0.4}_{-0.6}$	$9.60^{+0.14}_{-0.13}$	$4.5^{+2.5}_{-1.7}$	$4.8^{+2.1}_{-1.9}$	$85.4^{+112.8}_{-47.9}$
3C268.1	$-15.62^{+0.10}_{-0.07}$	0.02	$9.3^{+0.9}_{-0.9}$	$10.00^{+0.09}_{-0.14}$	$7.3^{+2.0}_{-2.4}$	$4.0^{+1.3}_{-0.8}$	$146.9^{+130.3}_{-79.0}$
3C280.0	$-15.59^{+0.12}_{-0.21}$	0.004	$8.4^{+1.1}_{-1.2}$	$10.00^{+0.09}_{-0.21}$	$6.7^{+3.4}_{-2.8}$	$4.9^{+1.7}_{-1.9}$	$133.4^{+172.1}_{-80.1}$
3C286.0	$-14.89^{+0.11}_{-0.15}$	0.008	$7.6^{+1.5}_{-0.9}$	$9.60^{+0.25}_{-0.09}$	$15.0^{+5.3}_{-5.1}$	$18.0^{+4.7}_{-5.5}$	$329.0^{+367.4}_{-186.0}$
3C289.0	$-15.60^{+0.09}_{-0.09}$	0.02	$8.2^{+0.4}_{-0.6}$	$9.40^{+0.11}_{-0.07}$	$3.0^{+1.1}_{-0.6}$	$4.4^{+1.1}_{-0.8}$	$54.2^{+51.2}_{-22.8}$
3C292.0	$-15.46^{+0.04}_{-0.06}$	0.008	$7.6^{+0.8}_{-0.7}$	$9.60^{+0.25}_{-0.30}$	$2.7^{+1.1}_{-1.2}$	$2.9^{+0.3}_{-0.3}$	$48.2^{+48.2}_{-28.9}$
3C309.1	$-14.80^{+0.09}_{-0.15}$	0.02	$7.7^{+0.4}_{-0.6}$	$9.10^{+0.05}_{-0.05}$	$7.6^{+2.3}_{-2.4}$	$26.0^{+6.6}_{-7.6}$	$153.6^{+144.8}_{-81.4}$
3C330.0	$-15.27^{+0.07}_{-0.08}$	0.02	$7.5^{+0.6}_{-0.5}$	$9.60^{+0.28}_{-0.27}$	$2.0^{+1.5}_{-0.8}$	$2.1^{+0.4}_{-0.4}$	$34.4^{+53.1}_{-19.0}$
3C334.0	$-14.62^{+0.12}_{-0.16}$	0.004	$7.4^{+0.7}_{-0.5}$	$9.50^{+0.09}_{-0.15}$	$7.6^{+3.3}_{-2.6}$	$11.0^{+3.3}_{-3.5}$	$153.6^{+180.7}_{-84.3}$
3C336.0	$-15.17^{+0.09}_{-0.10}$	0.008	$7.6^{+0.6}_{-0.7}$	$9.10^{+0.03}_{-0.05}$	$3.0^{+0.7}_{-0.7}$	$12.0^{+2.5}_{-2.4}$	$54.2^{+38.0}_{-23.5}$
3C337.0	$-15.39^{+0.10}_{-0.12}$	0.05	$8.8^{+1.6}_{-0.5}$	$9.80^{+0.18}_{-0.12}$	$2.8^{+1.1}_{-1.0}$	$2.4^{+0.6}_{-0.6}$	$50.2^{+49.2}_{-26.3}$
3C340.0	$-15.68^{+0.12}_{-0.11}$	0.004	$6.9^{+0.5}_{-0.3}$	$9.10^{+0.15}_{-0.05}$	$0.7^{+0.2}_{-0.2}$	$2.2^{+0.7}_{-0.5}$	$10.1^{+8.0}_{-4.5}$
3C343.0	$-15.46^{+0.14}_{-0.15}$	0.004	$8.7^{+2.0}_{-1.4}$	$10.00^{+0.09}_{-0.12}$	$10.0^{+4.6}_{-3.0}$	$6.5^{+2.3}_{-2.0}$	$208.9^{+263.1}_{-109.9}$
3C343.1	$-15.54^{+0.07}_{-0.07}$	0.05	$7.7^{+1.1}_{-0.8}$	$9.40^{+0.09}_{-0.10}$	$1.7^{+0.5}_{-0.4}$	$2.9^{+0.6}_{-0.5}$	$28.7^{+21.6}_{-12.5}$
3C352.0	$-15.37^{+0.03}_{-0.03}$	0.05	$7.9^{+0.6}_{-0.9}$	$10.00^{+0.06}_{-0.14}$	$9.1^{+1.4}_{-1.7}$	$4.0^{+0.3}_{-0.3}$	$188.0^{+131.9}_{-82.9}$
3C380.0	$-15.21^{+0.08}_{-0.19}$	0.004	$7.6^{+0.4}_{-0.9}$	$9.30^{+0.06}_{-0.15}$	$2.0^{+0.9}_{-0.8}$	$4.9^{+1.1}_{-1.7}$	$34.4^{+35.1}_{-18.6}$
3C427.1	$-15.52^{+0.05}_{-0.06}$	0.05	$7.6^{+0.9}_{-0.8}$	$10.00^{+0.03}_{-0.06}$	$3.0^{+0.5}_{-0.5}$	$1.2^{+0.2}_{-0.2}$	$54.2^{+32.4}_{-21.1}$
3C441.0	$-15.37^{+0.05}_{-0.07}$	0.05	$7.5^{+0.8}_{-0.6}$	$9.80^{+0.12}_{-0.11}$	$3.8^{+1.0}_{-0.7}$	$3.1^{+0.3}_{-0.4}$	$70.7^{+55.1}_{-29.4}$
3C455.0	$-15.72^{+0.14}_{-0.22}$	0.008	$7.0^{+0.5}_{-0.4}$	$9.10^{+0.06}_{-0.04}$	$0.3^{+0.1}_{-0.1}$	$0.9^{+0.3}_{-0.3}$	$3.8^{+2.6}_{-1.9}$

Table 11: Host fit parameters for the 3Cs at  $z < 0.5$ 

Name	$A_{Host}[\log(\frac{W}{m^2})]$	Z	$v$ [log(yr)]	Age [log(yr)]	$M_*$ [ $10^{10} M_\odot$ ]	$L_{Host}$ [ $10^{10} L_\odot$ ]	$M_{BH}$ [ $10^7 M_\odot$ ]
3C020.0	$-14.89^{+0.12}_{-0.15}$	0.008	$7.1^{+0.4}_{-0.4}$	$9.90^{+0.06}_{-0.08}$	$5.2^{+1.6}_{-1.5}$	$3.6^{+1.2}_{-1.1}$	$7.6^{+5.0}_{-3.2}$
3C031.0	$-12.21^{+0.04}_{-0.03}$	0.02	$6.6^{+0.2}_{-0.1}$	$9.50^{+0.01}_{-0.02}$	$10.0^{+0.3}_{-0.9}$	$13.0^{+1.1}_{-0.8}$	$15.8^{+4.8}_{-4.5}$
3C033.0	$-13.57^{+0.01}_{-0.02}$	0.02	$8.0^{+0.3}_{-0.4}$	$9.60^{+0.12}_{-0.11}$	$7.7^{+1.7}_{-1.5}$	$7.8^{+0.2}_{-0.3}$	$11.8^{+6.7}_{-4.2}$
3C033.1	$-14.82^{+0.11}_{-0.16}$	0.004	$7.8^{+0.3}_{-0.5}$	$9.10^{+0.08}_{-0.08}$	$1.6^{+0.6}_{-0.6}$	$5.3^{+1.7}_{-1.6}$	$2.0^{+1.4}_{-0.9}$
3C035.0	$-13.57^{+0.01}_{-0.02}$	0.05	$7.0^{+0.3}_{-0.4}$	$9.30^{+0.10}_{-0.22}$	$5.7^{+0.9}_{-1.6}$	$9.5^{+0.4}_{-0.4}$	$8.4^{+3.7}_{-3.6}$
3C047.0	$-14.85^{+0.15}_{-0.19}$	0.05	$7.2^{+0.6}_{-0.5}$	$9.90^{+0.08}_{-0.15}$	$48.0^{+19.0}_{-19.0}$	$29.0^{+12.0}_{-9.8}$	$91.8^{+96.4}_{-52.9}$
3C048.0	$-14.14^{+0.12}_{-0.15}$	0.004	$8.8^{+1.4}_{-1.2}$	$9.50^{+0.12}_{-0.09}$	$72.0^{+39.0}_{-38.0}$	$130.0^{+47.0}_{-41.0}$	$144.6^{+197.0}_{-98.5}$
3C079.0	$-14.68^{+0.10}_{-0.15}$	0.008	$8.6^{+0.5}_{-0.4}$	$9.60^{+0.07}_{-0.06}$	$10.0^{+3.9}_{-4.2}$	$17.0^{+5.4}_{-4.8}$	$15.8^{+13.6}_{-8.8}$
3C098.0	$-13.19^{+0.01}_{-0.01}$	0.05	$7.5^{+0.8}_{-0.6}$	$9.50^{+0.08}_{-0.03}$	$3.5^{+0.2}_{-0.2}$	$4.3^{+0.1}_{-0.1}$	$4.9^{+1.4}_{-1.0}$
3C109.0	$-14.22^{+0.16}_{-0.23}$	0.008	$10.0^{+0.5}_{-0.6}$	$9.80^{+0.03}_{-0.21}$	$67.0^{+31.0}_{-43.0}$	$64.0^{+37.0}_{-24.0}$	$133.4^{+161.5}_{-101.6}$
3C111.0	$-14.59^{+0.14}_{-0.24}$	0.008	$7.3^{+0.9}_{-0.5}$	$9.50^{+0.20}_{-0.06}$	$0.4^{+0.3}_{-0.2}$	$0.5^{+0.2}_{-0.2}$	$0.4^{+0.2}_{-0.2}$
3C120.0	$-13.60^{+0.05}_{-0.20}$	0.02	$6.7^{+0.5}_{-0.2}$	$9.50^{+0.04}_{-0.10}$	$1.6^{+0.2}_{-0.6}$	$2.2^{+0.3}_{-0.8}$	$2.0^{+0.7}_{-1.0}$
3C123.0	$-14.92^{+0.06}_{-0.09}$	0.05	$7.8^{+1.2}_{-0.9}$	$10.00^{+0.07}_{-0.18}$	$10.0^{+2.8}_{-3.0}$	$4.9^{+0.8}_{-1.0}$	$15.8^{+10.9}_{-7.6}$
3C153.0	$-14.82^{+0.04}_{-0.04}$	0.008	$8.5^{+0.8}_{-1.5}$	$9.30^{+0.19}_{-0.19}$	$5.9^{+1.2}_{-1.6}$	$15.0^{+4.8}_{-1.7}$	$8.8^{+4.5}_{-3.6}$
3C171.0	$-14.92^{+0.03}_{-0.04}$	0.008	$9.3^{+1.0}_{-1.6}$	$9.90^{+0.20}_{-0.21}$	$10.0^{+3.5}_{-2.9}$	$7.1^{+0.9}_{-0.7}$	$15.8^{+12.6}_{-7.1}$
3C173.1	$-14.43^{+0.03}_{-0.03}$	0.02	$10.0^{+0.4}_{-1.2}$	$10.00^{+0.07}_{-0.11}$	$61.0^{+11.0}_{-12.0}$	$33.0^{+2.3}_{-2.4}$	$120.1^{+84.8}_{-52.2}$
3C192.0	$-13.64^{+0.01}_{-0.01}$	0.05	$6.8^{+0.2}_{-0.2}$	$9.40^{+0.04}_{-0.05}$	$4.7^{+0.3}_{-0.3}$	$6.4^{+0.1}_{-0.2}$	$6.8^{+2.0}_{-1.6}$
3C200.0	$-15.11^{+0.03}_{-0.03}$	0.02	$7.4^{+0.7}_{-0.6}$	$9.50^{+0.10}_{-0.19}$	$17.0^{+4.7}_{-4.9}$	$22.0^{+1.3}_{-1.6}$	$28.7^{+21.1}_{-13.3}$
3C219.0	$-14.20^{+0.02}_{-0.02}$	0.05	$7.7^{+0.6}_{-1.0}$	$9.40^{+0.11}_{-0.07}$	$12.0^{+1.3}_{-1.3}$	$18.0^{+0.7}_{-0.8}$	$19.4^{+8.5}_{-5.9}$
3C234.0	$-14.57^{+0.13}_{-0.23}$	0.008	$8.7^{+0.4}_{-0.5}$	$9.40^{+0.09}_{-0.11}$	$5.1^{+1.9}_{-2.9}$	$11.0^{+3.6}_{-4.1}$	$7.5^{+5.6}_{-4.9}$
3C236.0	$-13.70^{+0.02}_{-0.02}$	0.008	$8.4^{+0.9}_{-0.9}$	$10.00^{+0.16}_{-0.11}$	$27.0^{+9.6}_{-5.7}$	$18.0^{+1.0}_{-1.0}$	$48.2^{+44.0}_{-20.1}$
3C249.1	$-14.14^{+0.09}_{-0.09}$	0.004	$8.1^{+1.0}_{-0.7}$	$9.10^{+0.30}_{-0.08}$	$24.0^{+8.6}_{-5.0}$	$91.0^{+31.0}_{-18.0}$	$42.3^{+38.2}_{-17.4}$
3C268.3	$-15.07^{+0.17}_{-0.17}$	0.05	$7.8^{+0.9}_{-0.9}$	$9.70^{+0.07}_{-0.24}$	$14.0^{+8.9}_{-6.2}$	$14.0^{+5.6}_{-4.4}$	$23.1^{+29.9}_{-13.4}$
3C273.0	$-13.27^{+0.03}_{-0.08}$	0.02	$7.1^{+0.2}_{-0.2}$	$9.20^{+0.03}_{-0.04}$	$62.0^{+9.6}_{-13.0}$	$140.0^{+8.2}_{-25.0}$	$122.3^{+81.3}_{-54.5}$
3C274.1	$-15.09^{+0.12}_{-0.11}$	0.02	$7.6^{+0.8}_{-0.2}$	$9.50^{+0.03}_{-0.08}$	$14.0^{+3.9}_{-4.3}$	$19.0^{+6.7}_{-4.0}$	$23.1^{+16.6}_{-10.9}$
3C285.0	$-13.82^{+0.02}_{-0.02}$	0.008	$7.7^{+0.2}_{-0.6}$	$9.50^{+0.04}_{-0.05}$	$5.8^{+0.6}_{-0.6}$	$8.5^{+0.3}_{-0.4}$	$8.6^{+3.2}_{-2.3}$
3C300.0	$-14.96^{+0.03}_{-0.03}$	0.004	$7.2^{+1.4}_{-0.5}$	$9.60^{+0.06}_{-0.05}$	$8.2^{+1.1}_{-1.9}$	$9.5^{+0.6}_{-0.6}$	$12.7^{+5.6}_{-5.0}$
3C305.0	$-13.04^{+0.01}_{-0.01}$	0.02	$7.8^{+0.8}_{-0.8}$	$9.80^{+0.04}_{-0.11}$	$17.0^{+0.8}_{-1.1}$	$13.0^{+0.2}_{-0.2}$	$28.7^{+10.8}_{-8.1}$
3C310.0	$-13.59^{+0.02}_{-0.03}$	0.004	$7.5^{+0.4}_{-0.8}$	$9.50^{+0.29}_{-0.08}$	$5.1^{+2.0}_{-1.2}$	$6.5^{+0.3}_{-0.4}$	$7.5^{+5.9}_{-2.8}$
3C315.0	$-14.23^{+0.01}_{-0.01}$	0.05	$8.8^{+0.2}_{-0.6}$	$9.80^{+0.04}_{-0.04}$	$6.3^{+0.7}_{-0.5}$	$5.7^{+0.2}_{-0.1}$	$9.4^{+3.7}_{-2.4}$
3C319.0	$-15.00^{+0.02}_{-0.04}$	0.02	$7.6^{+0.3}_{-0.5}$	$9.60^{+0.06}_{-0.05}$	$3.3^{+0.2}_{-0.4}$	$3.8^{+0.2}_{-0.2}$	$4.6^{+1.8}_{-1.2}$
3C321.0	$-13.74^{+0.06}_{-0.08}$	0.05	$8.1^{+0.9}_{-1.2}$	$9.60^{+0.14}_{-0.09}$	$13.0^{+4.9}_{-2.9}$	$14.0^{+2.4}_{-2.6}$	$21.3^{+18.4}_{-8.5}$
3C326.0	$-14.14^{+0.01}_{-0.01}$	0.05	$7.5^{+0.3}_{-0.4}$	$9.50^{+0.04}_{-0.05}$	$3.9^{+0.3}_{-0.3}$	$4.6^{+0.1}_{-0.1}$	$5.5^{+1.6}_{-1.2}$
3C341.0	$-15.14^{+0.01}_{-0.20}$	0.05	$8.6^{+0.4}_{-0.8}$	$9.80^{+0.12}_{-0.08}$	$21.0^{+12.0}_{-7.1}$	$20.0^{+8.4}_{-7.8}$	$36.4^{+45.2}_{-18.5}$
3C349.0	$-14.85^{+0.02}_{-0.03}$	0.02	$7.0^{+0.4}_{-0.4}$	$9.10^{+0.08}_{-0.05}$	$2.6^{+0.5}_{-0.3}$	$6.4^{+0.4}_{-0.4}$	$3.5^{+1.5}_{-0.8}$
3C351.0	$-14.00^{+0.10}_{-0.11}$	0.004	$8.4^{+1.8}_{-1.5}$	$9.90^{+0.07}_{-0.16}$	$210.0^{+70.0}_{-65.0}$	$170.0^{+59.0}_{-44.0}$	$479.6^{+538.2}_{-265.3}$
3C381.0	$-14.36^{+0.05}_{-0.05}$	0.02	$11.0^{+0.2}_{-0.3}$	$9.40^{+0.05}_{-0.05}$	$7.7^{+1.3}_{-1.3}$	$11.0^{+1.4}_{-1.5}$	$11.8^{+5.8}_{-4.0}$
3C382.0	$-13.09^{+0.03}_{-0.04}$	0.05	$7.3^{+0.5}_{-0.5}$	$9.60^{+0.10}_{-0.06}$	$18.0^{+1.8}_{-1.8}$	$20.0^{+1.7}_{-1.8}$	$30.6^{+14.1}_{-9.6}$
3C386.0	$-12.96^{+0.03}_{-0.03}$	0.05	$7.4^{+0.6}_{-0.5}$	$9.20^{+0.05}_{-0.09}$	$1.0^{+0.1}_{-0.2}$	$2.4^{+0.2}_{-0.2}$	$1.2^{+0.4}_{-0.3}$
3C388.0	$-13.80^{+0.02}_{-0.03}$	0.02	$7.5^{+0.8}_{-0.7}$	$9.40^{+0.05}_{-0.08}$	$8.8^{+0.8}_{-1.1}$	$12.0^{+0.7}_{-0.7}$	$13.7^{+5.3}_{-4.2}$
3C390.3	$-13.51^{+0.06}_{-0.10}$	0.05	$7.1^{+1.4}_{-0.3}$	$9.60^{+0.03}_{-0.04}$	$6.9^{+1.3}_{-1.5}$	$7.4^{+1.5}_{-1.6}$	$10.5^{+5.3}_{-3.9}$
3C401.0	$-14.80^{+0.02}_{-0.03}$	0.008	$7.9^{+0.6}_{-0.9}$	$9.80^{+0.17}_{-0.10}$	$7.1^{+2.0}_{-1.0}$	$6.4^{+0.3}_{-0.3}$	$10.8^{+7.1}_{-3.3}$
3C424.0	$-14.72^{+0.05}_{-0.06}$	0.02	$8.2^{+2.1}_{-0.6}$	$9.60^{+0.04}_{-0.04}$	$2.3^{+0.4}_{-0.4}$	$2.9^{+0.5}_{-0.4}$	$3.1^{+1.1}_{-0.9}$
3C433.0	$-13.80^{+0.09}_{-0.12}$	0.008	$7.3^{+0.7}_{-0.6}$	$9.10^{+0.14}_{-0.06}$	$6.2^{+2.6}_{-2.1}$	$16.0^{+3.6}_{-3.9}$	$9.3^{+7.9}_{-4.4}$
3C436.0	$-14.55^{+0.02}_{-0.04}$	0.05	$7.4^{+1.0}_{-0.7}$	$9.60^{+0.10}_{-0.14}$	$11.0^{+2.8}_{-1.8}$	$12.0^{+0.6}_{-0.7}$	$17.6^{+11.5}_{-6.1}$
3C438.0	$-14.44^{+0.03}_{-0.03}$	0.05	$7.3^{+0.5}_{-0.5}$	$10.00^{+0.13}_{-0.13}$	$57.0^{+13.0}_{-12.0}$	$29.0^{+1.9}_{-2.1}$	$111.3^{+86.9}_{-49.3}$
3C452.0	$-13.77^{+0.02}_{-0.03}$	0.05	$8.6^{+0.6}_{-0.7}$	$9.90^{+0.07}_{-0.05}$	$12.0^{+2.2}_{-1.7}$	$8.5^{+1.0}_{-0.6}$	$19.4^{+10.7}_{-6.4}$
3C459.0	$-14.59^{+0.07}_{-0.08}$	0.008	$7.5^{+0.7}_{-0.6}$	$9.20^{+0.08}_{-0.17}$	$5.0^{+1.5}_{-1.3}$	$14.0^{+2.7}_{-2.4}$	$7.3^{+4.7}_{-2.9}$

Table 12: AGN fit parameters for the 3Cs at  $0.5 < z < 1.0$ 

Name	$A_{AGN}[\log(\frac{W}{m\text{\AA}})]$	i [deg]	N	a	$\theta$ [deg]	$\tau$	$L_{AGN}[10^{11}L_{\odot}]$	$\frac{L_{AGN}}{L_{Edd}}$
3C006.1	$-15.08^{+0.05}_{-0.05}$	45	10.0	0.00	30	50	$9.2^{+1.3}_{-0.9}$	$0.0138^{+0.0246}_{-0.0079}$
3C022.0	$-14.57^{+0.03}_{-0.07}$	0	2.5	-2.00	30	30	$49.0^{+4.6}_{-7.7}$	$0.1076^{+0.2156}_{-0.0685}$
3C049.0	$-14.92^{+0.04}_{-0.07}$	15	5.0	-1.50	05	30	$7.0^{+0.6}_{-1.1}$	$0.1240^{+0.1506}_{-0.0736}$
3C055.0	$-14.43^{+0.07}_{-0.10}$	15	5.0	-0.50	30	30	$30.0^{+5.6}_{-5.2}$	$0.1945^{+0.5339}_{-0.1303}$
3C138.0	$-14.28^{+0.04}_{-0.05}$	15	2.5	-1.00	60	50	$49.0^{+5.3}_{-5.4}$	$0.3462^{+0.5185}_{-0.1884}$
3C147.0	$-14.36^{+0.04}_{-0.07}$	15	2.5	-1.00	30	30	$17.0^{+1.5}_{-2.5}$	$0.0979^{+0.0974}_{-0.0537}$
3C172.0	$-15.51^{+0.06}_{-0.15}$	75	5.0	0.00	60	30	$1.0^{+0.1}_{-0.3}$	$0.0084^{+0.0076}_{-0.0050}$
3C175.0	$-14.52^{+0.11}_{-0.11}$	0	5.0	-2.00	05	30	$31.0^{+8.7}_{-6.9}$	$0.0240^{+0.0426}_{-0.0140}$
3C175.1	$-14.72^{+0.01}_{-0.04}$	30	10.0	-1.00	45	30	$31.0^{+1.8}_{-2.2}$	$0.0226^{+0.0369}_{-0.0164}$
3C184.0	$-15.11^{+0.05}_{-0.06}$	45	10.0	0.00	30	30	$12.0^{+1.4}_{-1.5}$	$0.0474^{+0.0602}_{-0.0276}$
3C196.0	$-14.47^{+0.04}_{-0.04}$	0	2.5	-1.00	45	50	$46.0^{+3.3}_{-4.0}$	$0.0950^{+0.1724}_{-0.0505}$
3C207.0	$-14.55^{+0.05}_{-0.06}$	15	5.0	-1.50	60	30	$20.0^{+4.0}_{-2.2}$	$0.1111^{+0.1377}_{-0.0579}$
3C216.0	$-14.31^{+0.05}_{-0.08}$	0	2.5	-1.00	30	50	$34.0^{+4.5}_{-5.4}$	$0.2402^{+0.4834}_{-0.1555}$
3C220.1	$-15.30^{+0.04}_{-0.06}$	0	2.5	-1.00	30	30	$2.5^{+0.2}_{-0.3}$	$0.0367^{+0.0640}_{-0.0212}$
3C220.3	$-14.96^{+0.12}_{-0.22}$	75	7.5	0.00	30	50	$6.6^{+2.1}_{-2.7}$	$0.0301^{+0.0793}_{-0.0230}$
3C226.0	$-14.52^{+0.05}_{-0.05}$	45	7.5	0.00	30	50	$32.0^{+3.7}_{-3.6}$	$0.0651^{+0.1237}_{-0.0380}$
3C228.0	$-15.60^{+0.10}_{-0.07}$	75	10.0	-0.50	30	50	$0.9^{+0.2}_{-0.1}$	$0.0044^{+0.0056}_{-0.0021}$
3C254.0	$-14.51^{+0.03}_{-0.03}$	0	2.5	-1.00	45	30	$26.0^{+1.4}_{-1.7}$	$0.0467^{+0.0500}_{-0.0239}$
3C263.0	$-14.13^{+0.04}_{-0.04}$	0	2.5	-1.00	30	30	$44.0^{+4.1}_{-3.6}$	$0.0537^{+0.0549}_{-0.0271}$
3C263.1	$-15.27^{+0.05}_{-0.05}$	0	7.5	0.00	30	80	$6.8^{+0.9}_{-1.0}$	$0.0231^{+0.0323}_{-0.0129}$
3C265.0	$-14.43^{+0.02}_{-0.04}$	45	2.5	-1.00	30	30	$39.0^{+2.1}_{-3.2}$	$0.1427^{+0.1999}_{-0.0862}$
3C268.1	$-15.32^{+0.05}_{-0.06}$	30	10.0	-0.50	45	50	$8.8^{+1.0}_{-1.1}$	$0.0187^{+0.0264}_{-0.0100}$
3C280.0	$-14.77^{+0.03}_{-0.05}$	75	5.0	-1.00	60	50	$29.0^{+3.0}_{-2.0}$	$0.0679^{+0.1198}_{-0.0403}$
3C286.0	$-14.70^{+0.09}_{-0.17}$	0	2.5	-1.00	30	30	$24.0^{+5.9}_{-7.1}$	$0.0228^{+0.0425}_{-0.0152}$
3C289.0	$-15.12^{+0.02}_{-0.04}$	30	7.5	0.00	30	30	$11.0^{+0.5}_{-1.1}$	$0.0634^{+0.0507}_{-0.0340}$
3C292.0	$-15.35^{+0.04}_{-0.05}$	15	7.5	0.00	05	50	$3.3^{+0.3}_{-0.4}$	$0.0214^{+0.0374}_{-0.0119}$
3C309.1	$-14.47^{+0.03}_{-0.05}$	0	7.5	-0.50	30	50	$53.0^{+4.4}_{-6.0}$	$0.1078^{+0.1404}_{-0.0586}$
3C330.0	$-14.92^{+0.02}_{-0.03}$	45	7.5	-1.00	30	50	$5.0^{+0.2}_{-0.3}$	$0.0454^{+0.0609}_{-0.0285}$
3C334.0	$-14.11^{+0.05}_{-0.09}$	0	7.5	-0.50	05	30	$32.0^{+4.2}_{-5.6}$	$0.0651^{+0.0981}_{-0.0404}$
3C336.0	$-15.06^{+0.07}_{-0.08}$	15	2.5	-2.00	45	30	$16.0^{+2.3}_{-3.1}$	$0.0922^{+0.0940}_{-0.0485}$
3C337.0	$-15.51^{+0.12}_{-0.15}$	60	5.0	-0.50	30	50	$1.7^{+0.5}_{-0.5}$	$0.0106^{+0.0187}_{-0.0067}$
3C340.0	$-15.47^{+0.04}_{-0.14}$	45	7.5	-1.00	30	30	$3.2^{+0.4}_{-0.7}$	$0.0988^{+0.1029}_{-0.0563}$
3C343.0	$-14.51^{+0.02}_{-0.02}$	30	10.0	0.00	30	50	$50.0^{+2.0}_{-2.0}$	$0.0748^{+0.0893}_{-0.0430}$
3C343.1	$-15.54^{+0.06}_{-0.09}$	60	10.0	0.00	60	50	$2.5^{+0.4}_{-0.4}$	$0.0272^{+0.0277}_{-0.0144}$
3C352.0	$-15.60^{+0.06}_{-0.07}$	30	10.0	0.00	30	50	$2.7^{+0.3}_{-0.4}$	$0.0045^{+0.0045}_{-0.0022}$
3C380.0	$-14.17^{+0.05}_{-0.05}$	15	5.0	-1.50	45	50	$56.0^{+5.3}_{-7.3}$	$0.5080^{+0.7034}_{-0.2891}$
3C427.1	$-15.28^{+0.04}_{-0.05}$	75	10.0	0.00	45	50	$2.1^{+0.2}_{-0.2}$	$0.0121^{+0.0096}_{-0.0053}$
3C441.0	$-15.33^{+0.05}_{-0.07}$	45	7.5	0.00	05	30	$3.2^{+0.4}_{-0.5}$	$0.0141^{+0.0131}_{-0.0073}$
3C455.0	$-15.11^{+0.10}_{-0.13}$	30	5.0	-0.50	45	50	$3.2^{+0.8}_{-0.8}$	$0.2625^{+0.3838}_{-0.1468}$

Table 13: AGN fit parameters for the 3Cs at  $z < 0.5$ 

Name	$A_{AGN}[\log(\frac{W}{mz})]$	i [deg]	N	a	$\theta$ [deg]	$\tau$	$L_{AGN}[10^9 L_\odot]$	$\frac{L_{AGN}}{L_{Edd}}$
3C020.0	$-14.74^{+0.03}_{-0.07}$	45	5.0	-1.50	30	50	$52.0^{+7.6}_{-8.6}$	$0.0213^{+0.0211}_{-0.0106}$
3C031.0	$-14.39^{+0.23}_{-0.27}$	45	5.0	-0.50	30	30	$0.7^{+0.5}_{-0.3}$	$0.0001^{+0.0002}_{-0.0001}$
3C033.0	$-13.82^{+0.03}_{-0.04}$	60	7.5	-1.00	45	50	$42.0^{+3.6}_{-3.3}$	$0.0111^{+0.0077}_{-0.0046}$
3C033.1	$-14.19^{+0.03}_{-0.04}$	0	7.5	-0.50	30	30	$210.0^{+15.0}_{-18.0}$	$0.3224^{+0.2865}_{-0.1458}$
3C035.0	$-15.92^{+0.15}_{-0.24}$	30	7.5	-0.50	60	30	$0.5^{+0.2}_{-0.2}$	$0.0002^{+0.0002}_{-0.0001}$
3C047.0	$-14.09^{+0.05}_{-0.07}$	15	5.0	-1.50	30	30	$1900.0^{+160.0}_{-260.0}$	$0.0647^{+0.0374}_{-0.0374}$
3C048.0	$-13.64^{+0.06}_{-0.06}$	15	5.0	-1.50	45	50	$3900.0^{+510.0}_{-510.0}$	$0.0843^{+0.2149}_{-0.0533}$
3C079.0	$-14.11^{+0.03}_{-0.03}$	30	5.0	-0.50	30	30	$510.0^{+47.0}_{-48.0}$	$0.1006^{+0.1457}_{-0.0515}$
3C098.0	$-14.24^{+0.10}_{-0.10}$	30	2.5	0.00	30	30	$3.7^{+1.0}_{-0.8}$	$0.0024^{+0.0014}_{-0.0009}$
3C109.0	$-13.55^{+0.02}_{-0.04}$	15	5.0	-1.50	30	30	$2800.0^{+120.0}_{-360.0}$	$0.0656^{+0.2210}_{-0.0397}$
3C111.0	$-13.39^{+0.10}_{-0.11}$	0	2.5	-2.00	30	30	$87.0^{+25.0}_{-20.0}$	$0.6886^{+1.1840}_{-0.0969}$
3C120.0	$-13.24^{+0.10}_{-0.24}$	0	5.0	-1.00	30	50	$53.0^{+8.9}_{-25.0}$	$0.0814^{+0.0491}_{-0.0086}$
3C123.0	$-15.19^{+0.15}_{-0.15}$	75	2.5	-1.50	45	50	$31.0^{+7.7}_{-7.7}$	$0.0061^{+0.0035}_{-0.0079}$
3C153.0	$-15.64^{+0.10}_{-0.05}$	45	2.5	-1.00	30	30	$19.0^{+5.2}_{-2.3}$	$0.0068^{+0.0028}_{-0.0136}$
3C171.0	$-14.96^{+0.05}_{-0.05}$	15	7.5	-0.50	30	30	$63.0^{+10.0}_{-7.7}$	$0.0124^{+0.0063}_{-0.0007}$
3C173.1	$-15.80^{+0.19}_{-0.23}$	75	7.5	-2.00	45	50	$16.0^{+8.6}_{-6.4}$	$0.0004^{+0.0003}_{-0.0011}$
3C192.0	$-15.07^{+0.16}_{-0.16}$	30	2.5	-1.00	30	50	$2.6^{+1.2}_{-0.8}$	$0.0012^{+0.0005}_{-0.0127}$
3C200.0	$-15.51^{+0.15}_{-0.15}$	45	2.5	-2.00	05	30	$88.0^{+22.0}_{-25.0}$	$0.0096^{+0.0056}_{-0.0066}$
3C219.0	$-14.68^{+0.05}_{-0.05}$	0	2.5	-1.50	30	50	$69.0^{+7.7}_{-7.7}$	$0.0111^{+0.0042}_{-0.0042}$
3C234.0	$-13.41^{+0.01}_{-0.01}$	45	5.0	-1.00	30	30	$1400.0^{+28.0}_{-84.0}$	$0.5868^{+1.1776}_{-0.2728}$
3C236.0	$-14.62^{+0.18}_{-0.17}$	75	7.5	-1.00	30	30	$20.0^{+9.5}_{-6.5}$	$0.0013^{+0.0020}_{-0.0008}$
3C249.1	$-14.04^{+0.03}_{-0.06}$	0	2.5	-2.00	45	30	$1100.0^{+120.0}_{-100.0}$	$0.0814^{+0.0720}_{-0.0425}$
3C268.3	$-14.82^{+0.07}_{-0.09}$	0	5.0	-1.00	45	30	$250.0^{+38.0}_{-55.0}$	$0.0338^{+0.0592}_{-0.0223}$
3C273.0	$-12.89^{+0.09}_{-0.03}$	0	5.0	-2.00	45	30	$3600.0^{+580.0}_{-280.0}$	$0.0920^{+0.1005}_{-0.0410}$
3C274.1	$-15.89^{+0.13}_{-0.27}$	60	5.0	-0.50	45	50	$26.0^{+11.0}_{-13.0}$	$0.0035^{+0.0060}_{-0.0025}$
3C285.0	$-14.15^{+0.06}_{-0.07}$	45	5.0	-0.50	30	30	$33.0^{+5.0}_{-5.3}$	$0.0120^{+0.0069}_{-0.0047}$
3C300.0	$-15.85^{+0.12}_{-0.23}$	30	7.5	-1.00	30	50	$11.0^{+3.2}_{-4.8}$	$0.0027^{+0.0030}_{-0.0017}$
3C305.0	$-14.18^{+0.11}_{-0.15}$	45	10.0	0.00	45	30	$8.2^{+2.5}_{-2.3}$	$0.0009^{+0.0007}_{-0.0004}$
3C310.0	$-15.43^{+0.16}_{-0.23}$	30	5.0	-1.50	60	50	$0.9^{+0.4}_{-0.4}$	$0.0004^{+0.0005}_{-0.0003}$
3C315.0	$-15.42^{+0.10}_{-0.13}$	60	5.0	0.00	60	50	$3.7^{+0.9}_{-1.0}$	$0.0012^{+0.0008}_{-0.0006}$
3C319.0	$-16.23^{+0.18}_{-0.20}$	15	2.5	-2.00	30	30	$2.3^{+1.3}_{-0.8}$	$0.0016^{+0.0018}_{-0.0009}$
3C321.0	$-13.39^{+0.03}_{-0.03}$	45	10.0	0.00	05	30	$290.0^{+16.0}_{-22.0}$	$0.0426^{+0.0325}_{-0.0215}$
3C326.0	$-15.96^{+0.17}_{-0.26}$	60	7.5	-2.00	30	50	$0.8^{+0.4}_{-0.3}$	$0.0005^{+0.0004}_{-0.0003}$
3C341.0	$-14.31^{+0.05}_{-0.05}$	30	5.0	-1.00	60	30	$1300.0^{+100.0}_{-130.0}$	$0.1117^{+0.1335}_{-0.0669}$
3C349.0	$-15.01^{+0.06}_{-0.08}$	30	5.0	-1.00	30	30	$42.0^{+5.8}_{-7.1}$	$0.0374^{+0.0181}_{-0.0157}$
3C351.0	$-13.70^{+0.06}_{-0.12}$	45	5.0	-1.50	45	30	$3400.0^{+550.0}_{-890.0}$	$0.0222^{+0.0354}_{-0.0144}$
3C381.0	$-14.15^{+0.02}_{-0.03}$	15	5.0	-1.00	05	30	$170.0^{+12.0}_{-13.0}$	$0.0449^{+0.0276}_{-0.0171}$
3C382.0	$-13.36^{+0.07}_{-0.05}$	0	5.0	-2.00	05	30	$130.0^{+19.0}_{-15.0}$	$0.0133^{+0.0089}_{-0.0052}$
3C386.0	$-15.64^{+0.16}_{-0.22}$	30	7.5	-2.00	30	50	$0.1^{+0.1}_{-0.1}$	$0.0001^{+0.0001}_{-0.0001}$
3C388.0	$-15.64^{+0.17}_{-0.23}$	15	5.0	-1.00	45	30	$1.6^{+0.8}_{-0.7}$	$0.0004^{+0.0004}_{-0.0002}$
3C390.3	$-13.43^{+0.09}_{-0.09}$	15	7.5	-1.50	30	30	$98.0^{+19.0}_{-18.0}$	$0.0293^{+0.0265}_{-0.0134}$
3C401.0	$-15.72^{+0.13}_{-0.23}$	45	7.5	-1.00	45	50	$7.3^{+2.8}_{-3.1}$	$0.0021^{+0.0021}_{-0.0014}$
3C424.0	$-15.43^{+0.13}_{-0.15}$	45	5.0	-1.50	30	30	$5.5^{+1.8}_{-1.8}$	$0.0056^{+0.0051}_{-0.0029}$
3C433.0	$-13.55^{+0.06}_{-0.09}$	30	2.5	-1.00	30	30	$240.0^{+38.0}_{-44.0}$	$0.0808^{+0.0967}_{-0.0451}$
3C436.0	$-15.37^{+0.16}_{-0.14}$	45	7.5	-0.50	30	30	$18.0^{+8.1}_{-5.0}$	$0.0032^{+0.0039}_{-0.0018}$
3C438.0	$-16.20^{+0.15}_{-0.24}$	30	2.5	-1.50	05	30	$5.9^{+2.4}_{-2.6}$	$0.0002^{+0.0003}_{-0.0001}$
3C452.0	$-14.04^{+0.02}_{-0.04}$	45	10.0	-1.00	30	30	$49.0^{+2.6}_{-5.0}$	$0.0079^{+0.0045}_{-0.0033}$
3C459.0	$-13.82^{+0.02}_{-0.02}$	30	7.5	0.00	05	80	$600.0^{+29.0}_{-27.0}$	$0.2571^{+0.1908}_{-0.1079}$

Table 14: FIR fit parameters for the 3Cs at  $0.5 < z < 1.0$ 

Name	$A_{FIR}[\log(\frac{W}{m^2})]$	$T_{FIR}$ [K]	$SFR[\frac{M_{\odot}}{yr}]$	$L_{FIR}[10^{11} L_{\odot}]$	$M_{Dust}[10^7 M_{\odot}]$	$M_{Dust}/M_{\star} [‰]$
3C006.1	$-15.33^{+0.07}_{-0.08}$	$34.0^{+2.0}_{-2.0}$	$73.0^{+12.9}_{-12.5}$	$4.2^{+0.7}_{-0.7}$	$11.58^{+0.17}_{-4.76}$	0.116
3C022.0	$-15.28^{+0.13}_{-0.21}$	$31.0^{+0.4}_{-0.4}$	$106.0^{+36.5}_{-40.0}$	$6.1^{+2.1}_{-2.3}$	$27.18^{+3.92}_{-7.15}$	0.383
3C049.0	$-15.14^{+0.07}_{-0.09}$	$37.0^{+0.9}_{-0.9}$	$53.8^{+9.0}_{-10.2}$	$3.1^{+0.5}_{-0.6}$	$4.07^{+0.42}_{-1.13}$	0.370
3C055.0	$-14.48^{+0.05}_{-0.06}$	$37.0^{+0.5}_{-0.5}$	$364.8^{+43.4}_{-48.6}$	$21.0^{+2.5}_{-2.8}$	$26.45^{+1.14}_{-3.82}$	0.980
3C138.0	$-14.82^{+0.09}_{-0.09}$	$37.0^{+0.6}_{-0.6}$	$173.7^{+41.7}_{-34.7}$	$10.0^{+2.4}_{-2.0}$	$14.38^{+0.22}_{-1.49}$	0.575
3C147.0	$-14.64^{+0.06}_{-0.09}$	$43.0^{+0.8}_{-0.8}$	$125.1^{+19.1}_{-22.6}$	$7.2^{+1.1}_{-1.3}$	$6.15^{+0.84}_{-1.58}$	0.205
3C172.0	$-15.27^{+0.04}_{-0.04}$	$32.0^{+3.1}_{-3.1}$	$26.1^{+2.3}_{-2.4}$	$1.5^{+0.1}_{-0.1}$	$4.86^{+1.25}_{-1.98}$	0.232
3C175.0	$-15.00^{+0.15}_{-0.23}$	$28.0^{+0.9}_{-0.9}$	$125.1^{+48.6}_{-50.4}$	$7.2^{+2.8}_{-2.9}$	$41.59^{+1.83}_{-13.85}$	0.231
3C175.1	$-15.16^{+0.03}_{-0.03}$	$21.0^{+1.0}_{-1.0}$	$133.7^{+10.8}_{-7.8}$	$7.7^{+0.6}_{-0.4}$	$237.31^{+16.34}_{-110.93}$	1.249
3C184.0	$-15.37^{+0.05}_{-0.06}$	$28.0^{+2.4}_{-2.4}$	$100.7^{+11.5}_{-13.9}$	$5.8^{+0.7}_{-0.8}$	$40.23^{+12.32}_{-14.69}$	0.958
3C196.0	$-15.21^{+0.08}_{-0.16}$	$30.0^{+1.3}_{-1.3}$	$102.5^{+20.8}_{-33.0}$	$5.9^{+1.2}_{-1.9}$	$31.95^{+5.11}_{-6.54}$	0.426
3C207.0	$-15.16^{+0.10}_{-0.15}$	$38.0^{+0.7}_{-0.7}$	$64.3^{+16.2}_{-19.1}$	$3.7^{+0.9}_{-1.1}$	$5.83^{+0.38}_{-0.38}$	0.188
3C216.0	$-14.48^{+0.05}_{-0.09}$	$34.0^{+1.1}_{-1.1}$	$295.3^{+36.5}_{-55.6}$	$17.0^{+2.1}_{-3.2}$	$39.63^{+4.16}_{-5.84}$	1.585
3C220.1	$-15.41^{+0.06}_{-0.06}$	$35.0^{+0.2}_{-0.2}$	$62.5^{+4.0}_{-4.7}$	$3.6^{+0.2}_{-0.2}$	$3.31^{+0.65}_{-0.77}$	0.255
3C220.3	$-14.21^{+0.05}_{-0.05}$	$27.0^{+0.8}_{-0.8}$	$555.8^{+62.5}_{-57.3}$	$32.0^{+3.6}_{-3.3}$	$163.51^{+57.80}_{-105.61}$	4.419
3C226.0	$-15.39^{+0.12}_{-0.23}$	$29.0^{+0.9}_{-0.9}$	$59.1^{+19.1}_{-24.3}$	$3.4^{+1.1}_{-1.4}$	$18.23^{+2.19}_{-2.80}$	0.240
3C228.0	$-15.36^{+0.03}_{-0.05}$	$34.0^{+0.7}_{-0.7}$	$24.3^{+1.5}_{-2.8}$	$1.4^{+0.1}_{-0.2}$	$4.05^{+0.28}_{-0.43}$	0.116
3C254.0	$-15.30^{+0.10}_{-0.13}$	$34.0^{+1.0}_{-1.0}$	$55.6^{+14.6}_{-14.6}$	$3.2^{+0.8}_{-0.8}$	$8.96^{+0.72}_{-2.75}$	0.105
3C263.0	$-14.85^{+0.10}_{-0.19}$	$47.0^{+1.0}_{-1.0}$	$112.9^{+31.3}_{-40.0}$	$6.5^{+1.8}_{-2.3}$	$2.05^{+0.13}_{-0.13}$	0.017
3C263.1	$-15.40^{+0.06}_{-0.09}$	$23.0^{+1.5}_{-1.5}$	$59.1^{+8.7}_{-10.8}$	$3.4^{+0.5}_{-0.6}$	$74.21^{+23.47}_{-23.89}$	1.546
3C265.0	$-15.04^{+0.03}_{-0.10}$	$39.0^{+0.5}_{-0.5}$	$128.5^{+8.7}_{-26.1}$	$7.4^{+0.5}_{-1.5}$	$9.92^{+1.62}_{-2.55}$	0.220
3C268.1	$-15.33^{+0.04}_{-0.04}$	$22.0^{+1.1}_{-1.1}$	$104.2^{+9.7}_{-10.1}$	$6.0^{+0.6}_{-0.6}$	$151.52^{+32.03}_{-49.26}$	2.076
3C280.0	$-15.16^{+0.10}_{-0.11}$	$37.0^{+1.3}_{-1.3}$	$165.0^{+43.4}_{-36.5}$	$9.5^{+2.5}_{-2.1}$	$14.54^{+1.64}_{-2.03}$	0.217
3C286.0	$-14.85^{+0.09}_{-0.16}$	$31.0^{+1.2}_{-1.2}$	$225.8^{+50.4}_{-67.7}$	$13.0^{+2.9}_{-3.9}$	$43.79^{+2.83}_{-11.23}$	0.292
3C289.0	$-15.37^{+0.05}_{-0.05}$	$27.0^{+0.9}_{-0.9}$	$93.8^{+10.6}_{-10.4}$	$5.4^{+0.6}_{-0.6}$	$42.87^{+4.95}_{-8.27}$	1.429
3C292.0	$-15.52^{+0.04}_{-0.06}$	$34.0^{+2.0}_{-2.0}$	$31.3^{+3.0}_{-4.0}$	$1.8^{+0.2}_{-0.2}$	$5.62^{+1.19}_{-1.20}$	0.208
3C309.1	$-15.19^{+0.13}_{-0.22}$	$27.0^{+1.5}_{-1.5}$	$119.9^{+43.4}_{-46.9}$	$6.9^{+2.5}_{-2.7}$	$64.59^{+5.07}_{-26.71}$	0.850
3C330.0	$-15.25^{+0.04}_{-0.07}$	$35.0^{+0.9}_{-0.9}$	$29.5^{+3.0}_{-4.2}$	$1.7^{+0.2}_{-0.2}$	$4.42^{+0.09}_{-0.75}$	0.221
3C334.0	$-15.15^{+0.10}_{-0.18}$	$32.0^{+0.7}_{-0.7}$	$38.2^{+10.2}_{-13.5}$	$2.2^{+0.6}_{-0.8}$	$16.17^{+0.40}_{-2.57}$	0.213
3C336.0	$-15.38^{+0.10}_{-0.18}$	$20.0^{+0.7}_{-0.7}$	$83.4^{+20.8}_{-27.8}$	$4.8^{+1.2}_{-1.6}$	$264.41^{+11.99}_{-103.80}$	8.814
3C337.0	$-15.59^{+0.12}_{-0.14}$	$24.0^{+3.1}_{-3.1}$	$20.8^{+6.3}_{-5.6}$	$1.2^{+0.4}_{-0.3}$	$17.72^{+7.07}_{-10.58}$	0.633
3C340.0	$-15.43^{+0.02}_{-0.07}$	$30.0^{+0.8}_{-0.8}$	$46.9^{+2.8}_{-6.8}$	$2.7^{+0.2}_{-0.4}$	$16.02^{+1.09}_{-4.66}$	2.391
3C343.0	$-14.96^{+0.05}_{-0.06}$	$25.0^{+3.0}_{-3.0}$	$260.6^{+31.3}_{-33.0}$	$15.0^{+1.8}_{-1.9}$	$130.96^{+4.29}_{-125.32}$	1.310
3C343.1	$-15.28^{+0.03}_{-0.04}$	$42.0^{+2.2}_{-2.2}$	$60.8^{+4.5}_{-5.4}$	$3.5^{+0.3}_{-0.3}$	$1.85^{+1.02}_{-1.62}$	0.109
3C352.0	$-15.47^{+0.03}_{-0.03}$	$38.0^{+0.8}_{-0.8}$	$46.9^{+3.0}_{-3.6}$	$2.7^{+0.2}_{-0.2}$	$5.04^{+0.63}_{-1.41}$	0.055
3C380.0	$-14.46^{+0.08}_{-0.12}$	$41.0^{+0.4}_{-0.4}$	$330.0^{+69.5}_{-83.4}$	$19.0^{+4.0}_{-4.8}$	$17.61^{+4.74}_{-5.92}$	0.880
3C427.1	$-15.47^{+0.03}_{-0.03}$	$23.0^{+1.1}_{-1.1}$	$20.8^{+1.6}_{-1.4}$	$1.2^{+0.1}_{-0.1}$	$19.72^{+0.41}_{-9.41}$	0.657
3C441.0	$-15.35^{+0.04}_{-0.06}$	$32.0^{+1.6}_{-1.6}$	$45.2^{+4.7}_{-5.7}$	$2.6^{+0.3}_{-0.3}$	$10.16^{+0.20}_{-3.76}$	0.267
3C455.0	$-15.49^{+0.14}_{-0.13}$	$33.0^{+1.9}_{-1.9}$	$16.8^{+6.1}_{-4.3}$	$1.0^{+0.4}_{-0.2}$	$2.86^{+0.23}_{-0.99}$	1.023

Table 15: FIR fit parameters for the 3Cs at  $z < 0.5$ 

Name	$A_{FIR}[\log(\frac{W}{m^2})]$	$T_{FIR}$ [K]	$SFR[\frac{M_{\odot}}{yr}]$	$L_{FIR}[10^9 L_{\odot}]$	$M_{Dust}[10^7 M_{\odot}]$	$M_{Dust}/M_{\star}[0/00]$
3C020.0	$-14.66^{+0.05}_{-0.03}$	$22.0^{+0.3}_{-0.3}$	$8.2^{+1.1}_{-0.6}$	$47.0^{+6.1}_{-3.4}$	$5.74^{+0.28}_{-0.63}$	1.103
3C031.0	$-13.39^{+0.05}_{-0.27}$	$23.0^{+0.7}_{-0.7}$	$1.0^{+0.1}_{-0.5}$	$6.0^{+0.8}_{-2.8}$	$0.90^{+0.07}_{-0.24}$	0.090
3C033.0	$-14.19^{+0.07}_{-0.12}$	$30.0^{+0.6}_{-0.6}$	$2.3^{+0.5}_{-0.5}$	$13.0^{+2.6}_{-3.7}$	$0.50^{+0.07}_{-0.16}$	0.065
3C033.1	$-15.00^{+0.13}_{-0.21}$	$40.0^{+0.6}_{-0.6}$	$4.2^{+1.4}_{-1.5}$	$24.0^{+8.2}_{-8.9}$	$0.33^{+0.02}_{-0.02}$	0.204
3C035.0	$-15.41^{+0.13}_{-0.27}$	$21.0^{+0.5}_{-0.5}$	$0.2^{+0.1}_{-0.1}$	$1.1^{+0.4}_{-0.5}$	$0.50^{+0.06}_{-0.08}$	0.088
3C047.0	$-14.82^{+0.12}_{-0.13}$	$29.0^{+2.3}_{-2.3}$	$43.4^{+14.4}_{-11.6}$	$250.0^{+83.0}_{-67.0}$	$10.15^{+2.52}_{-3.73}$	0.211
3C048.0	$-13.55^{+0.03}_{-0.04}$	$43.0^{+0.7}_{-0.7}$	$573.2^{+45.2}_{-55.6}$	$3300.0^{+260.0}_{-320.0}$	$26.27^{+3.29}_{-6.29}$	0.365
3C079.0	$-15.14^{+0.10}_{-0.19}$	$31.0^{+0.5}_{-0.5}$	$6.4^{+1.7}_{-2.3}$	$37.0^{+9.5}_{-13.0}$	$2.40^{+0.63}_{-0.96}$	0.240
3C098.0	$-14.66^{+0.14}_{-0.22}$	$34.0^{+1.4}_{-1.4}$	$0.2^{+0.1}_{-0.1}$	$1.1^{+0.4}_{-0.5}$	$0.02^{+0.00}_{-0.01}$	0.005
3C109.0	$-15.00^{+0.13}_{-0.31}$	$31.0^{+0.4}_{-0.4}$	$13.9^{+4.5}_{-6.8}$	$80.0^{+26.0}_{-39.0}$	$7.68^{+0.64}_{-1.60}$	0.115
3C111.0	$-13.92^{+0.09}_{-0.14}$	$29.0^{+1.9}_{-1.9}$	$3.0^{+0.6}_{-0.8}$	$17.0^{+3.7}_{-5.7}$	$0.71^{+0.01}_{-0.37}$	1.923
3C120.0	$-13.59^{+0.12}_{-0.18}$	$30.0^{+0.6}_{-0.6}$	$2.8^{+0.9}_{-1.0}$	$16.0^{+5.2}_{-5.6}$	$0.90^{+0.06}_{-0.22}$	0.562
3C123.0	$-15.05^{+0.10}_{-0.12}$	$66.0^{+2.0}_{-2.0}$	$5.6^{+1.4}_{-1.3}$	$32.0^{+8.2}_{-7.7}$	$0.04^{+0.00}_{-0.00}$	0.004
3C153.0	$-15.46^{+0.04}_{-0.06}$	$32.0^{+1.9}_{-1.9}$	$3.6^{+0.3}_{-0.5}$	$21.0^{+2.0}_{-2.9}$	$0.79^{+0.11}_{-0.25}$	0.133
3C171.0	$-15.24^{+0.08}_{-0.10}$	$33.0^{+2.4}_{-2.4}$	$4.3^{+0.9}_{-0.9}$	$25.0^{+5.0}_{-5.4}$	$0.78^{+0.10}_{-0.30}$	0.078
3C173.1	$-15.28^{+0.11}_{-0.18}$	$35.0^{+0.8}_{-0.8}$	$6.4^{+1.9}_{-2.3}$	$37.0^{+11.0}_{-13.0}$	$0.86^{+0.06}_{-0.21}$	0.014
3C192.0	$-14.92^{+0.12}_{-0.22}$	$33.0^{+1.6}_{-1.6}$	$0.5^{+0.2}_{-0.2}$	$2.7^{+0.9}_{-1.1}$	$0.05^{+0.01}_{-0.03}$	0.011
3C200.0	$-15.40^{+0.08}_{-0.10}$	$28.0^{+2.5}_{-2.5}$	$14.1^{+2.6}_{-3.0}$	$81.0^{+15.0}_{-17.0}$	$5.07^{+1.66}_{-1.85}$	0.298
3C219.0	$-15.27^{+0.15}_{-0.19}$	$32.0^{+0.8}_{-0.8}$	$2.1^{+0.9}_{-0.7}$	$12.0^{+5.0}_{-4.1}$	$0.37^{+0.03}_{-0.11}$	0.031
3C234.0	$-14.96^{+0.11}_{-0.22}$	$30.0^{+0.6}_{-0.6}$	$4.9^{+1.5}_{-1.9}$	$28.0^{+8.4}_{-11.0}$	$2.56^{+0.26}_{-0.73}$	0.502
3C236.0	$-14.51^{+0.14}_{-0.19}$	$28.0^{+1.3}_{-1.3}$	$3.6^{+1.4}_{-1.3}$	$21.0^{+8.2}_{-7.4}$	$0.93^{+0.23}_{-0.62}$	0.035
3C249.1	$-14.59^{+0.13}_{-0.20}$	$47.0^{+0.9}_{-0.9}$	$36.5^{+12.2}_{-13.4}$	$210.0^{+70.0}_{-77.0}$	$0.95^{+0.28}_{-0.39}$	0.040
3C268.3	$-15.08^{+0.11}_{-0.12}$	$39.0^{+1.7}_{-1.7}$	$17.4^{+5.0}_{-4.3}$	$100.0^{+29.0}_{-25.0}$	$1.44^{+0.17}_{-0.59}$	0.103
3C273.0	$-13.92^{+0.19}_{-0.25}$	$31.0^{+0.2}_{-0.2}$	$36.5^{+19.1}_{-16.3}$	$210.0^{+110.0}_{-94.0}$	$9.94^{+3.35}_{-3.88}$	0.160
3C274.1	$-15.43^{+0.20}_{-0.17}$	$29.0^{+1.5}_{-1.5}$	$10.6^{+5.9}_{-3.5}$	$61.0^{+34.0}_{-20.0}$	$3.30^{+0.50}_{-0.94}$	0.235
3C285.0	$-14.01^{+0.04}_{-0.05}$	$32.0^{+1.7}_{-1.7}$	$6.8^{+0.6}_{-0.7}$	$39.0^{+3.5}_{-4.1}$	$1.26^{+0.23}_{-0.28}$	0.217
3C300.0	$-15.48^{+0.08}_{-0.10}$	$27.0^{+0.4}_{-0.4}$	$3.3^{+0.7}_{-0.7}$	$19.0^{+3.8}_{-4.1}$	$1.52^{+0.15}_{-0.39}$	0.186
3C305.0	$-13.85^{+0.06}_{-0.09}$	$28.0^{+0.5}_{-0.5}$	$2.4^{+0.4}_{-0.5}$	$14.0^{+2.3}_{-2.6}$	$0.87^{+0.02}_{-0.12}$	0.051
3C310.0	$-15.11^{+0.09}_{-0.26}$	$21.0^{+0.6}_{-0.6}$	$0.2^{+0.1}_{-0.1}$	$1.4^{+0.5}_{-0.6}$	$0.53^{+0.06}_{-0.12}$	0.105
3C315.0	$-15.00^{+0.07}_{-0.08}$	$30.0^{+0.9}_{-0.9}$	$1.3^{+0.2}_{-0.2}$	$7.7^{+1.3}_{-1.2}$	$0.35^{+0.04}_{-0.05}$	0.055
3C319.0	$-15.24^{+0.04}_{-0.06}$	$22.0^{+0.4}_{-0.4}$	$2.6^{+0.2}_{-0.3}$	$15.0^{+1.3}_{-1.9}$	$3.64^{+0.52}_{-1.30}$	1.102
3C321.0	$-13.44^{+0.03}_{-0.04}$	$39.0^{+1.7}_{-1.7}$	$36.5^{+2.4}_{-3.1}$	$210.0^{+14.0}_{-18.0}$	$1.59^{+0.49}_{-0.95}$	0.123
3C326.0	$-15.30^{+0.11}_{-0.19}$	$25.0^{+0.3}_{-0.3}$	$0.5^{+0.1}_{-0.2}$	$2.6^{+0.7}_{-0.9}$	$0.30^{+0.00}_{-0.04}$	0.077
3C341.0	$-15.39^{+0.12}_{-0.21}$	$27.0^{+0.9}_{-0.9}$	$13.4^{+4.2}_{-5.2}$	$77.0^{+24.0}_{-30.0}$	$6.35^{+0.34}_{-1.76}$	0.302
3C349.0	$-15.40^{+0.07}_{-0.14}$	$25.0^{+1.4}_{-1.4}$	$2.1^{+0.4}_{-0.6}$	$12.0^{+2.1}_{-3.3}$	$1.65^{+0.33}_{-0.55}$	0.634
3C351.0	$-14.14^{+0.12}_{-0.12}$	$48.0^{+1.8}_{-1.8}$	$154.6^{+52.1}_{-38.2}$	$890.0^{+300.0}_{-220.0}$	$3.16^{+0.08}_{-0.76}$	0.015
3C381.0	$-14.96^{+0.14}_{-0.19}$	$24.0^{+1.4}_{-1.4}$	$3.3^{+1.3}_{-1.2}$	$19.0^{+7.6}_{-7.0}$	$3.14^{+0.89}_{-0.89}$	0.408
3C382.0	$-14.62^{+0.18}_{-0.23}$	$28.0^{+0.3}_{-0.3}$	$0.9^{+0.4}_{-0.3}$	$4.9^{+2.3}_{-2.0}$	$0.35^{+0.09}_{-0.13}$	0.020
3C386.0	$-14.66^{+0.18}_{-0.17}$	$26.0^{+0.6}_{-0.6}$	$0.1^{+0.0}_{-0.0}$	$0.3^{+0.2}_{-0.1}$	$0.03^{+0.00}_{-0.00}$	0.033
3C388.0	$-15.70^{+0.17}_{-0.22}$	$30.0^{+1.3}_{-1.3}$	$0.2^{+0.1}_{-0.1}$	$1.1^{+0.5}_{-0.4}$	$0.08^{+0.01}_{-0.02}$	0.009
3C390.3	$-14.37^{+0.09}_{-0.27}$	$43.0^{+0.5}_{-0.5}$	$1.4^{+0.3}_{-0.7}$	$8.2^{+2.0}_{-3.8}$	$0.05^{+0.02}_{-0.03}$	0.007
3C401.0	$-15.43^{+0.10}_{-0.13}$	$30.0^{+0.7}_{-0.7}$	$1.9^{+0.5}_{-0.5}$	$11.0^{+2.8}_{-2.7}$	$0.46^{+0.03}_{-0.10}$	0.065
3C424.0	$-15.60^{+0.13}_{-0.17}$	$24.0^{+1.3}_{-1.3}$	$0.5^{+0.2}_{-0.1}$	$2.6^{+1.0}_{-0.9}$	$0.40^{+0.10}_{-0.11}$	0.174
3C433.0	$-14.06^{+0.13}_{-0.18}$	$26.0^{+0.6}_{-0.6}$	$9.9^{+3.5}_{-3.5}$	$57.0^{+20.0}_{-20.0}$	$5.31^{+0.08}_{-1.11}$	0.857
3C436.0	$-15.03^{+0.07}_{-0.09}$	$25.0^{+1.5}_{-1.5}$	$5.6^{+1.0}_{-1.1}$	$32.0^{+5.5}_{-6.2}$	$3.79^{+0.90}_{-1.22}$	0.345
3C438.0	$-15.21^{+0.08}_{-0.15}$	$25.0^{+2.3}_{-2.3}$	$7.3^{+1.4}_{-2.1}$	$42.0^{+8.2}_{-12.0}$	$5.09^{+0.69}_{-3.24}$	0.089
3C452.0	$-14.74^{+0.16}_{-0.19}$	$36.0^{+0.8}_{-0.8}$	$1.3^{+0.6}_{-0.4}$	$7.3^{+3.3}_{-2.5}$	$0.07^{+0.02}_{-0.03}$	0.006
3C459.0	$-13.82^{+0.02}_{-0.03}$	$30.0^{+1.4}_{-1.4}$	$93.8^{+5.4}_{-5.9}$	$540.0^{+31.0}_{-34.0}$	$27.37^{+4.26}_{-6.37}$	5.474

Table 16: Monochromatic luminosities for the 3Cs at  $0.5 < z < 1.0$ 

Name	$\nu L_{\nu}^{30GHz} [\log(L_{\odot})]$	$\nu L_{\nu}^{178MHz} [\log(L_{\odot})]$	$\nu L_{\nu}^{30 \mu m} [\log(L_{\odot})]$	$\nu L_{\nu}^{60 \mu m} [\log(L_{\odot})]$	$\nu L_{\nu}^{100 \mu m} [\log(L_{\odot})]$
3C006.1	$10.69 \pm 0.023$	$10.28 \pm 0.003$	$11.57 \pm 0.015$	$11.63 \pm 0.009$	$11.56 \pm 0.098$
3C022.0	$10.57 \pm 0.011$	$10.33 \pm 0.007$	$12.19 \pm 0.016$	$11.97 \pm 0.006$	$11.75 \pm 0.085$
3C049.0	$10.26 \pm 0.014$	$9.76 \pm 0.009$	$11.47 \pm 0.020$	$11.42 \pm 0.033$	$11.26 \pm 0.082$
3C055.0	$10.23 \pm 0.031$	$10.38 \pm 0.065$	$12.28 \pm 0.007$	$12.29 \pm 0.008$	$12.07 \pm 0.041$
3C138.0	$11.24 \pm 0.012$	$10.15 \pm 0.033$	$12.19 \pm 0.014$	$11.99 \pm 0.009$	$11.80 \pm 0.020$
3C147.0	$11.08 \pm 0.006$	$10.22 \pm 0.003$	$11.85 \pm 0.007$	$11.79 \pm 0.007$	$11.68 \pm 0.082$
3C172.0	$10.09 \pm 0.007$	$9.77 \pm 0.003$	$10.81 \pm 0.016$	$11.01 \pm 0.015$	$11.07 \pm 0.046$
3C175.0	$10.28 \pm 0.041$	$10.33 \pm 0.004$	$12.01 \pm 0.013$	$11.76 \pm 0.017$	$11.72 \pm 0.086$
3C175.1	$10.50 \pm 0.031$	$10.15 \pm 0.019$	$11.32 \pm 0.092$	$11.55 \pm 0.020$	$11.73 \pm 0.105$
3C184.0	$10.49 \pm 0.017$	$10.35 \pm 0.001$	$11.64 \pm 0.035$	$11.74 \pm 0.016$	$11.70 \pm 0.019$
3C196.0	$11.33 \pm 0.010$	$10.97 \pm 0.004$	$12.08 \pm 0.013$	$11.80 \pm 0.011$	$11.75 \pm 0.012$
3C207.0	$11.08 \pm 0.021$	$10.01 \pm 0.001$	$11.70 \pm 0.013$	$11.49 \pm 0.001$	$11.46 \pm 0.001$
3C216.0	$10.97 \pm 0.013$	$10.21 \pm 0.004$	$12.16 \pm 0.012$	$12.16 \pm 0.002$	$12.09 \pm 0.010$
3C220.1	$10.01 \pm 0.016$	$9.99 \pm 0.002$	$11.06 \pm 0.003$	$11.12 \pm 0.003$	$11.07 \pm 0.086$
3C220.3	$10.38 \pm 0.073$	$10.14 \pm 0.002$	$11.78 \pm 0.036$	$12.09 \pm 0.019$	$12.23 \pm 0.200$
3C226.0	$10.25 \pm 0.018$	$10.32 \pm 0.004$	$12.11 \pm 0.012$	$11.92 \pm 0.010$	$11.43 \pm 0.008$
3C228.0	$10.28 \pm 0.011$	$9.93 \pm 0.005$	$10.88 \pm 0.019$	$11.09 \pm 0.006$	$11.10 \pm 0.009$
3C254.0	$10.27 \pm 0.014$	$10.33 \pm 0.009$	$11.84 \pm 0.016$	$11.49 \pm 0.015$	$11.45 \pm 0.086$
3C263.0	$10.35 \pm 0.022$	$10.02 \pm 0.002$	$12.08 \pm 0.006$	$11.77 \pm 0.024$	$11.33 \pm 0.001$
3C263.1	$10.47 \pm 0.022$	$10.32 \pm 0.009$	$11.36 \pm 0.005$	$11.45 \pm 0.001$	$11.48 \pm 0.002$
3C265.0	$10.35 \pm 0.009$	$10.42 \pm 0.005$	$12.17 \pm 0.003$	$11.98 \pm 0.001$	$11.73 \pm 0.087$
3C268.1	$11.28 \pm 0.010$	$10.54 \pm 0.002$	$11.57 \pm 0.003$	$11.61 \pm 0.003$	$11.67 \pm 0.032$
3C280.0	$11.03 \pm 0.009$	$10.67 \pm 0.003$	$12.12 \pm 0.009$	$11.99 \pm 0.006$	$11.81 \pm 0.007$
3C286.0	$11.60 \pm 0.005$	$10.39 \pm 0.002$	$12.02 \pm 0.010$	$12.03 \pm 0.004$	$11.96 \pm 0.047$
3C289.0	$10.50 \pm 0.013$	$10.28 \pm 0.005$	$11.70 \pm 0.005$	$11.67 \pm 0.005$	$11.65 \pm 0.019$
3C292.0	$10.38 \pm 0.024$	$9.98 \pm 0.002$	$11.13 \pm 0.019$	$11.24 \pm 0.001$	$11.24 \pm 0.001$
3C309.1	$11.42 \pm 0.006$	$10.46 \pm 0.001$	$12.31 \pm 0.008$	$12.05 \pm 0.004$	$11.82 \pm 0.087$
3C330.0	$10.52 \pm 0.019$	$10.11 \pm 0.001$	$11.38 \pm 0.026$	$11.17 \pm 0.064$	$11.19 \pm 0.035$
3C334.0	$9.92 \pm 0.034$	$9.81 \pm 0.009$	$12.04 \pm 0.004$	$11.83 \pm 0.054$	$11.59 \pm 0.031$
3C336.0	$10.61 \pm 0.017$	$10.34 \pm 0.005$	$11.64 \pm 0.003$	$11.56 \pm 0.001$	$11.62 \pm 0.087$
3C337.0	$10.34 \pm 0.015$	$9.93 \pm 0.009$	$10.85 \pm 0.014$	$11.06 \pm 0.025$	$10.97 \pm 0.078$
3C340.0	$10.39 \pm 0.021$	$10.05 \pm 0.002$	$11.28 \pm 0.014$	$11.39 \pm 0.006$	$11.45 \pm 0.080$
3C343.0	$10.97 \pm 0.018$	$10.07 \pm 0.014$	$12.34 \pm 0.057$	$12.34 \pm 0.012$	$11.94 \pm 0.283$
3C343.1	$10.52 \pm 0.009$	$9.74 \pm 0.016$	$11.28 \pm 0.012$	$11.45 \pm 0.007$	$11.12 \pm 0.268$
3C352.0	$10.17 \pm 0.028$	$10.16 \pm 0.001$	$11.23 \pm 0.005$	$11.39 \pm 0.005$	$11.39 \pm 0.086$
3C380.0	$11.47 \pm 0.010$	$10.74 \pm 0.002$	$12.26 \pm 0.015$	$12.15 \pm 0.002$	$12.06 \pm 0.118$
3C427.1	$10.10 \pm 0.009$	$10.13 \pm 0.001$	$10.51 \pm 0.041$	$10.72 \pm 0.021$	$10.90 \pm 0.115$
3C441.0	$10.40 \pm 0.013$	$10.04 \pm 0.003$	$11.18 \pm 0.015$	$11.29 \pm 0.011$	$11.39 \pm 0.085$
3C455.0	$10.02 \pm 0.022$	$9.75 \pm 0.001$	$10.84 \pm 0.010$	$10.83 \pm 0.010$	$10.90 \pm 0.068$



Table 17: Monochromatic luminosities for the 3Cs at  $z < 0.5$ 

Name	$\nu L_{\nu}^{30GHz} [log(L_{\odot})]$	$\nu L_{\nu}^{178MHz} [log(L_{\odot})]$	$\nu L_{\nu}^{30 \mu m} [log(L_{\odot})]$	$\nu L_{\nu}^{60 \mu m} [log(L_{\odot})]$	$\nu L_{\nu}^{100 \mu m} [log(L_{\odot})]$
3C020.0	$9.65 \pm 0.010$	$9.16 \pm 0.003$	$10.46 \pm 0.049$	$10.40 \pm 0.066$	$10.24 \pm 0.014$
3C031.0	$7.21 \pm 0.058$	$6.58 \pm 0.009$	$8.98 \pm 0.157$	$9.31 \pm 0.001$	$9.57 \pm 0.045$
3C033.0	$8.73 \pm 0.034$	$8.24 \pm 0.002$	$10.38 \pm 0.028$	$10.17 \pm 0.046$	$9.94 \pm 0.096$
3C033.1	$9.05 \pm 0.041$	$8.72 \pm 0.002$	$11.01 \pm 0.033$	$10.68 \pm 0.003$	$10.29 \pm 0.001$
3C035.0	$7.94 \pm 0.047$	$7.71 \pm 0.001$	$8.64 \pm 0.067$	$8.76 \pm 0.039$	$9.05 \pm 0.012$
3C047.0	$9.96 \pm 0.011$	$9.89 \pm 0.003$	$11.71 \pm 0.078$	$11.84 \pm 0.112$	$11.18 \pm 0.036$
3C048.0	$10.45 \pm 0.008$	$9.88 \pm 0.006$	$12.33 \pm 0.044$	$12.45 \pm 0.019$	$12.31 \pm 0.077$
3C079.0	$9.44 \pm 0.015$	$9.34 \pm 0.001$	$11.45 \pm 0.016$	$11.15 \pm 0.008$	$10.70 \pm 0.132$
3C098.0	$8.00 \pm 0.057$	$7.59 \pm 0.004$	$9.36 \pm 0.034$	$9.06 \pm 0.036$	$8.71 \pm 0.125$
3C109.0	$9.86 \pm 0.048$	$9.41 \pm 0.001$	$12.07 \pm 0.019$	$11.69 \pm 0.020$	$11.20 \pm 0.063$
3C111.0	$9.02 \pm 0.050$	$8.08 \pm 0.018$	$10.37 \pm 0.094$	$10.19 \pm 0.095$	$10.03 \pm 0.130$
3C120.0	$8.73 \pm 0.011$	$6.84 \pm 0.023$	$10.40 \pm 0.034$	$10.32 \pm 0.048$	$10.20 \pm 0.067$
3C123.0	$10.43 \pm 0.011$	$10.05 \pm 0.003$	$10.35 \pm 0.079$	$10.32 \pm 0.006$	$10.00 \pm 0.018$
3C153.0	$9.62 \pm 0.015$	$9.19 \pm 0.003$	$10.07 \pm 0.036$	$10.21 \pm 0.010$	$10.27 \pm 0.046$
3C171.0	$9.40 \pm 0.011$	$9.12 \pm 0.003$	$10.58 \pm 0.031$	$10.37 \pm 0.002$	$10.33 \pm 0.069$
3C173.1	$9.40 \pm 0.016$	$9.22 \pm 0.006$	$10.05 \pm 0.073$	$10.35 \pm 0.016$	$10.48 \pm 0.067$
3C192.0	$8.54 \pm 0.017$	$7.91 \pm 0.006$	$9.30 \pm 0.039$	$9.37 \pm 0.036$	$9.16 \pm 0.136$
3C200.0	$9.83 \pm 0.015$	$9.60 \pm 0.006$	$10.60 \pm 0.006$	$10.78 \pm 0.005$	$10.80 \pm 0.012$
3C219.0	$9.35 \pm 0.015$	$9.15 \pm 0.005$	$10.47 \pm 0.038$	$10.15 \pm 0.005$	$9.95 \pm 0.080$
3C234.0	$9.26 \pm 0.008$	$9.09 \pm 0.002$	$11.82 \pm 0.036$	$11.42 \pm 0.009$	$10.65 \pm 0.084$
3C236.0	$8.95 \pm 0.027$	$8.01 \pm 0.027$	$10.08 \pm 0.028$	$10.14 \pm 0.041$	$10.07 \pm 0.197$
3C249.1	$9.56 \pm 0.013$	$9.20 \pm 0.007$	$11.57 \pm 0.025$	$11.32 \pm 0.017$	$11.00 \pm 0.140$
3C268.3	$9.81 \pm 0.014$	$9.26 \pm 0.003$	$10.97 \pm 0.043$	$10.96 \pm 0.008$	$10.90 \pm 0.117$
3C273.0	$10.99 \pm 0.005$	$9.37 \pm 0.005$	$11.96 \pm 0.065$	$11.49 \pm 0.094$	$11.31 \pm 0.138$
3C274.1	$9.75 \pm 0.035$	$9.56 \pm 0.016$	$10.44 \pm 0.030$	$10.62 \pm 0.001$	$10.69 \pm 0.036$
3C285.0	$8.30 \pm 0.037$	$7.78 \pm 0.002$	$10.37 \pm 0.043$	$10.53 \pm 0.032$	$10.48 \pm 0.010$
3C300.0	$9.48 \pm 0.018$	$9.24 \pm 0.002$	$9.93 \pm 0.032$	$10.08 \pm 0.009$	$10.20 \pm 0.077$
3C305.0	$7.59 \pm 0.026$	$7.42 \pm 0.001$	$9.82 \pm 0.061$	$10.04 \pm 0.010$	$10.04 \pm 0.028$
3C310.0	$7.67 \pm 0.029$	$8.17 \pm 0.010$	$8.65 \pm 0.094$	$8.88 \pm 0.003$	$9.08 \pm 0.029$
3C315.0	$8.78 \pm 0.016$	$8.42 \pm 0.007$	$9.45 \pm 0.128$	$9.66 \pm 0.007$	$9.79 \pm 0.002$
3C319.0	$8.86 \pm 0.016$	$8.81 \pm 0.006$	$9.52 \pm 0.046$	$9.80 \pm 0.001$	$10.05 \pm 0.107$
3C321.0	$8.54 \pm 0.008$	$8.19 \pm 0.006$	$11.35 \pm 0.024$	$11.36 \pm 0.024$	$10.94 \pm 0.184$
3C326.0	$8.27 \pm 0.080$	$8.09 \pm 0.010$	$8.98 \pm 0.085$	$9.04 \pm 0.099$	$9.30 \pm 0.030$
3C341.0	$9.66 \pm 0.021$	$9.52 \pm 0.005$	$11.47 \pm 0.013$	$11.09 \pm 0.016$	$10.82 \pm 0.054$
3C349.0	$9.33 \pm 0.008$	$8.85 \pm 0.004$	$10.31 \pm 0.047$	$10.19 \pm 0.001$	$10.04 \pm 0.038$
3C351.0	$9.91 \pm 0.032$	$9.41 \pm 0.041$	$12.04 \pm 0.037$	$11.86 \pm 0.012$	$11.55 \pm 0.060$
3C381.0	$9.19 \pm 0.011$	$8.63 \pm 0.006$	$10.93 \pm 0.037$	$10.39 \pm 0.118$	$10.22 \pm 0.001$
3C382.0	$8.63 \pm 0.020$	$7.87 \pm 0.008$	$10.37 \pm 0.054$	$9.94 \pm 0.130$	$9.65 \pm 0.122$
3C386.0	$7.22 \pm 0.042$	$6.72 \pm 0.039$	$7.98 \pm 0.239$	$8.19 \pm 0.001$	$8.44 \pm 0.009$
3C388.0	$8.69 \pm 0.009$	$8.31 \pm 0.002$	$9.10 \pm 0.033$	$9.13 \pm 0.021$	$9.14 \pm 0.023$
3C390.3	$8.71 \pm 0.007$	$8.13 \pm 0.001$	$10.63 \pm 0.030$	$10.22 \pm 0.018$	$9.56 \pm 0.187$
3C401.0	$9.29 \pm 0.014$	$8.98 \pm 0.001$	$9.69 \pm 0.012$	$9.83 \pm 0.007$	$9.91 \pm 0.046$
3C424.0	$8.56 \pm 0.023$	$8.38 \pm 0.002$	$9.47 \pm 0.033$	$9.40 \pm 0.008$	$9.32 \pm 0.011$
3C433.0	$9.03 \pm 0.015$	$8.79 \pm 0.003$	$11.07 \pm 0.026$	$10.90 \pm 0.063$	$10.65 \pm 0.045$
3C436.0	$9.18 \pm 0.020$	$8.95 \pm 0.002$	$10.09 \pm 0.002$	$10.33 \pm 0.001$	$10.41 \pm 0.024$
3C438.0	$9.56 \pm 0.008$	$9.69 \pm 0.001$	$9.97 \pm 0.033$	$10.24 \pm 0.009$	$10.53 \pm 0.149$
3C452.0	$8.52 \pm 0.039$	$8.51 \pm 0.020$	$10.41 \pm 0.049$	$9.93 \pm 0.137$	$9.47 \pm 0.128$
3C459.0	$9.34 \pm 0.011$	$9.18 \pm 0.006$	$11.49 \pm 0.056$	$11.70 \pm 0.024$	$11.68 \pm 0.020$

## A.2. Maps

No Maps available in preprint.

